LONDON-WEST MIDLANDS ENVIRONMENTAL STATEMENT

Volume 5 | Technical Appendices

CFA22 | Whittington to Handsacre

Whittington to Handsacre river modelling report (WR-004-015)

Water resources

November 2013

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Appendix WR-004-015

Environmental topic:	Water resources and flood risk assessment	WR
Appendix name:	Modelling	004
Community forum area:	Whittington to Handsacre	022

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1 Overarching modelling approach

1.1 Introduction

1.1.1 This section of the Proposed Scheme will cross numerous watercourses with the potential for affecting flood risk. Hydraulic modelling has been carried out to assess the current (baseline) river flood risks at each of these watercourse crossings and the potential impacts of the proposed culvert and viaduct structures. Therefore, the primary objective of this assessment was to assess the impact of the proposed scheme on river flood risk.

1.1.2 The outcome of this assessment will aid the design to determine the type and dimension of structures required to convey the watercourse flows; and mitigation measures for any remaining residual flood risk.

1.1.3 A hydraulic modelling assessment of flood risk was undertaken for watercourses affected by this section of the Proposed Scheme. These watercourses were grouped into seven community forum areas (CFA) in this section of the Proposed Scheme. Existing hydraulic models of the watercourses have been utilised where available; and new river hydraulic models were built for the other watercourses. This report describes the hydraulic modelling processes and outcomes of this assessment.

1.1.4 The main conclusions from this modelling report form the basis of the river flood risk section in the Flood Risk Assessment for CFA22 – Whittington to Handsacre (WR-003-022). These conclusions are also reported within the Water Resources and Flood Risk Assessment section of Volume 2 of the Environmental Statement (ES).

1.2 Hydrology

1.2.1 Watercourses with existing hydraulic models adopted standard Flood Estimation Handbook (FEH) techniques for hydrological assessment. The hydrology of these models was reviewed for suitability for use in this study.

1.2.2 For the watercourses with no existing hydraulic models, hydrological assessments were undertaken in this assessment to determine the design flows.

1.2.3 The hydrological catchments of the watercourses to each of the route crossings have been determined from the FEH CD-ROM[1] for watercourses represented in this data set. For the purposes of this assessment it was assumed that catchment boundaries as represented in the FEH CD-ROM were correct, therefore a detailed assessment of catchment boundaries has not been completed. The catchment descriptors have also been taken from the FEH CD-ROM and updated for urban expansion to 2012, using Equation 6.8 in Volume 5 of the FEH[2]. This is a standard industry technique.

1.2.4 River flows at watercourse crossing locations were determined using the Revitalised Flood Hydrograph (ReFH) method[3] in the first instance. In line with the current Environment Agency flood estimation guidance[4], the ReFH method is deemed

[1] Centre for Ecology and Hydrology (2009) *FEH CD-ROM Version 3, ©NERC (CEH).*
[2] Centre for Ecology & Hydrology. (1999). *Flood Estimation Handbook – Volume 5: Catchment Descriptors*.
[3] Centre for Ecology & Hydrology. (2007). *The revitalised FSR/FEH rainfall-run-off method: Supplementary Report No. 1*.

acceptable for the majority of catchments along the route and is the most time efficient method for determining flows for studies where numerous flows are required.

1.2.5 The ReFH method is not considered acceptable for all catchments, in this case those classed as highly permeable. Based on the FEH CD-ROM catchment descriptors, a number of the catchments are classed as highly permeable and hence in line with current Environment Agency guidelines[4], an alternative method was required. Therefore at these locations, the FEH Statistical method, with a permeable adjustment was utilised, as recommended in the guidelines.

1.2.6 Not all watercourses crossed by the route were represented in the FEH CD-ROM; therefore, the catchment boundaries could not be determined using the FEH CD-ROM. In these instances, catchment boundaries have been determined through the use of topographic data from Light Detection and Ranging (LiDAR) data and Ordnance Survey (OS) mapping at a 1:10,000 scale. At locations of uncertainty, a slightly larger catchment has been assumed as a conservative approach. Flows for these catchments were determined through a conservative area scaling method. Based on the flows estimated for FEH CD-ROM represented catchments, a maximum flow rate of 1.4 and 2.6m^3/s per km^2 was calculated for the 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability events respectively. These flows rates, along with a 10% error allowance (to prevent an underestimation of flow), were used as scaling factors.

1.2.7 The estimated peak flows were used as either a constant inflow boundary or as a full hydrograph. The peak flows estimated using this method were for the 1 in 20 (5%) annual probability, 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability events. Flow during the 1 in 100 (1%) annual probability event with an allowance for climate change was estimated by factoring the 1 in 100 (1%) annual probability flow by 20%.

1.3 Hydraulics

General approach

1.3.1 The hydraulic modelling approach depended on the characteristics of the particular watercourse and floodplain hydraulics. The approach of either steady or unsteady modelling was based on whether there were rapid increases or decreases in flows, flood storage areas or structure impacts on channel/floodplain flows. The modelling approach also varied based on requirements of assessing the flow routes either in one-dimension (one dimensional) or two-dimensions (two dimensional).

1.3.2 The modelling approach adopted in this study was as follows:

- if the modelling was utilised for sizing the culvert crossings on watercourses with no significant floodplain attenuation or structure impacts, steady state one dimensional modelling was adopted;
- if there was significant floodplain attenuation and/or structure impacts on channel/floodplain flows, one dimensional hydrodynamic modelling was

[4] Environment Agency (2012) *Flood estimation guidelines (197_08).*

adopted; and

- if there was significant floodplain attenuation and/or structure impacts on channel/floodplain flows, and a requirement for accurately defining the flood extents, two dimensional or a one dimensional-two dimensional linked modelling was adopted.

1.3.3 Existing models were first reviewed to assess their suitability for use. If more recent data such as topography was available the models were updated accordingly. If the level of detail within the model, such as the floodplain, was not appropriate, the model was upgraded accordingly.

1.3.4 The hydraulic modelling approach was based on the Environment Agency guidelines[5].

1.3.5 Two industry standard modelling packages have been utilised as part of this assessment: ISIS (version 3.6) and TUFLOW (version 2012). ISIS[6] is software developed by Halcrow mainly used for one dimensional hydraulic modelling of river flooding. TUFLOW is software developed by BMT WBM[7] for two dimensional hydraulic modelling of river, estuarine and coastal flooding.

Hierarchical approach

1.3.6 Any existing Environment Agency models for the watercourses were used to assess the current and future flood risk impacts of the route crossing any watercourses.

1.3.7 For watercourses without existing hydraulic models, the modelling process was carried out in a phased manner to assess the baseline flood risk and impacts of the proposed scheme. In the first phase, the watercourses with culverted crossings were modelled as simple unsteady one dimensional hydraulic models, to assess the adequacy of culverts in conveying flood flows. In the second phase, watercourses for both culverted and viaduct crossings were modelled as two dimensional hydrodynamic models to define the flood extents and assess the impacts of the various structures on flood risk. The two dimensional model outputs were then used to inform the design team of flood risk.

1.3.8 All the models were run for the 1 in 100 (1%) annual probability with an allowance for climate change and 1 in 1000 (0.1%) annual probability. Some of the models were run for the 1 in 20 (5%) annual probability where the potential impacts on flood risk could affect vulnerable receptors.

1.3.9 The 1 in 100 (1%) annual probability with an allowance for climate change peak water levels for the baseline and proposed scheme were compared upstream and downstream of the crossing to assess the impact on flood risk. The scheme impact on flood risk and the width of the 1 in 100 (1%) annual probability with an allowance for climate change flood extents, defined the type of structure to be used at the crossings i.e. culvert or viaduct and the dimensions of culverts/viaducts. The structure type was selected based on its adequacy in conveying flood flows without significantly affecting flood risk.

[5] Environment Agency (2009), *Requirements for completing computer river modelling for flood risk assessments – Guidance for developers (Version 3.0).*
[6] Halcrow Limited (2012), ISIS (3.6).
[7] BMT WBM (2010), *TUFLOW User Manual.*

1.3.10 The peak water levels for the 1 in 1000 (0.1%) annual probability event confirmed whether the vertical alignment met the design criteria (refer to Section 3 of the Flood Risk Assessment WR-003-022).

Input data

1.3.11 The topographic data used was LiDAR data that was flown in 2012, covering the extent of the Proposed Scheme, providing data as fine as up to 0.2m horizontal resolution. This data was used to create digital terrain models (DTM) for use within the hydraulic models. In most cases, the DTM has been resized to a 1m resolution for suitability in two dimensional models. For watercourses without existing hydraulic models, there were no topographic surveys available and hence river sections and floodplain topography were derived from these DTMs.

1.3.12 For existing models, the floodplain topography was updated with this DTM. The channel topography in these models was taken from topographic surveys undertaken previously.

1.3.13 Inflows to the watercourses were taken from the hydrological assessments as discussed in Section 0 of this report.

1.3.14 The data for the proposed scheme model scenario was taken from the scheme drawings.

One dimensional modelling

1.3.15 In the first phase, one dimensional ISIS models were constructed representing a 200m to 300m reach of the watercourse. The purpose of these models was to assess the adequacy of culverted crossings in conveying flows. These models used the LiDAR data to define extended cross sections which included the channel and floodplain topography. The roughness of the channels and floodplains is defined by the Manning's roughness parameter. The Manning's roughness values were based on the particular land use type as observed from aerial photographs. Steady state flows were applied as upstream inflow boundaries and a normal depth boundary was applied at the downstream extent. The normal depth boundary was based on the bed slope of the topography at that location and is considered suitable for the purpose of the modelling.

1.3.16 The Proposed Scheme model included rectangular conduit units to represent the structures at the crossings. There were two types of culverts adopted: a minimum culvert size of 2m by 1.5m and a maximum culvert size of 4m by 2m. The dimensions adopted here represent the flow area of the culvert rather than the full dimensions of the culvert that would need to be larger to accommodate depressed inverts and mammal ledges as appropriate. The lengths of the culverts were based on the width of the route crossings as defined in the scheme design.

Two dimensional modelling

1.3.17 In the second phase, unsteady state two dimensional TUFLOW models were built to accurately define the flood extents and floodplain attenuation. The two dimensional models were built on a 5m cell resolution with LiDAR data used to create the DTM, which defined the floodplain and channel topography.

1.3.18 It should be noted that components within a 2D TUFLOW model such as SXZ, HX, Z-polygon, Z-Shape polygons, etc., are based on naming conventions as defined in the TUFLOW manual[7].

1.3.19 The Manning's roughness values of the channels and floodplains were based on the particular land use type as observed from aerial photographs.

1.3.20 The inflow to each watercourse was applied upstream using a TUFLOW boundary condition polyline layer, linking it to a flow time series within a boundary condition database. The flow type is either constant flow or hydrograph flow, depending on the attenuation within the floodplain. A flow-head (HQ) polyline layer was used for the downstream boundary, based on the slope of the floodplain at that location; which was considered suitable for the scale and level of detail of the modelling. The models have been run at a two second timestep for varying durations.

1.3.21 The proposed scheme model was built by adding either culvert or viaduct structures to the baseline model at the watercourse crossings.

1.3.22 Viaduct structures have been modelled by adding route embankments as Z-polygon or Z-Shape polygon layers with an opening at the viaduct crossing. The Z-polygon or Z-Shape polygon layers are Geographic Information System (GIS) polygons with elevations. Where piers were modelled, they were represented as flow constriction (FC) shape layers. The soffit levels were not added into the model. This was because the 1 in 1000 (0.1%) annual probability modelled peak flood levels, along with sufficient clearance, will form the basis of designing the soffit heights (refer to Section 3 of the Flood Risk Assessment WR-003-022).

1.3.23 Culvert structures have been modelled by adding a one dimensional network layer representing the extent of the culvert, the length of which was determined by the width of the route at the crossing point (including embankment earthworks and any landscaping). Inverts were defined at the inflow and outflow points of the culvert extracted from the LiDAR DTM for the area. This one dimensional network layer was connected to the two dimensional domain with a SXZ point link, a GIS point used in the modelling software for one dimensional-two dimensional linking. An embankment was modelled across the route as a Z-polygon layer, covering the extent of the upstream floodplain at the route crossing so that all flow was routed through the culvert.

One dimensional-two dimensional linked modelling

1.3.24 In certain cases where existing one dimensional models were not representing complex channel-floodplain interactions accurately, dynamically linked one dimensional-two dimensional models were constructed. The channel component was represented in one dimension and the floodplain component in two dimensions. These models were built using ISIS-TUFLOW.

1.3.25 The flows between the one dimensional and two dimensional model components were controlled via a GIS polyline layer (HX layer), the spill levels of which are defined by the channel bank levels or DTM levels.

1.3.26 In the proposed scheme scenarios, the viaduct structures are represented as discussed earlier in the two dimensional modelling section (Section 1.3.22 of this report).

Sensitivity assessments

1.3.27 Sensitivity assessments have been undertaken on various parameters of the models to reflect the uncertainties and impacts on modelled flood levels. Assessments have been carried out on inflows and culvert blockages. In the case of viaduct crossings, sensitivity was undertaken on inflows.

1.3.28 Sensitivity assessment on inflows was carried out by varying the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability flows by 20%. This was undertaken for the baseline and post-scheme scenarios, unless stated otherwise.

1.3.29 Sensitivity assessment has also been carried out on proposed scheme scenarios with culvert structures by adding 10% blockage. Resulting models have been run for the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability events.

1.4 Assumptions and limitations

Hydrology

1.4.1 The catchment boundaries and descriptors as taken from the FEH CD-ROM are correct and accurately represent the catchments in reality.

1.4.2 For catchments not classed as highly permeable, the ReFH method results in the most accurate estimation of flow at the location of the crossings in comparison to other methods.

1.4.3 The FEH Statistical method with permeable adjustment results in the most accurate estimation of flow for catchments classed as highly permeable.

1.4.4 The area scaling method, which is based on area, results in conservative flow estimates for catchments which are not represented in the FEH CD-ROM (refer to Section 0 of this report for detail).

1.4.5 There are no external influences on flow at the location of the crossing, such as significant abstractions or discharges.

1.4.6 A 20% allowance for climate change on peak flow rates has been adopted for the 1 in 100 (1%) annual probability with an allowance for climate change event.

Hydraulic modelling

1.4.7 Only river flood risk was considered during the hydraulic modelling in this assessment.

1.4.8 For watercourses without existing hydraulic models, the watercourse geometry was extracted from the LiDAR DTM with the channel width defined by the 5m cell resolution of the two dimensional model. Therefore, the watercourse geometry is not well defined, the consequence of which is an underestimate of the channel conveyance and hence, an overestimation of the floodplain inundation.

1.4.9 There will be certain watercourses with road crossing structures upstream or downstream of a route crossing, causing a significant impact on hydraulics. Ordnance Survey mapping and aerial photography were used to assess the location of the

structures. The inverts of any culvert structure were assumed to be the channel bed levels from the LiDAR DTM; and structure widths as the width of the channel.

1.4.10 In the proposed scheme for models involving viaducts, the structure was represented by the piers and embankments. The scheme drawings were used to obtain the footprint of the piers and the dimensions incorporated into the model. The soffits of the viaducts were not modelled as the design approach for the structures is to include a suitable clearance between peak flood level and the structure soffit.

2 Modelling at watercourse crossings

2.1 Overview

2.1.1 River modelling undertaken at the various watercourse crossings for this study area are summarised in Table 1, along with the modelling methodologies adopted. Figure 1 identifies the location of each of these structures.

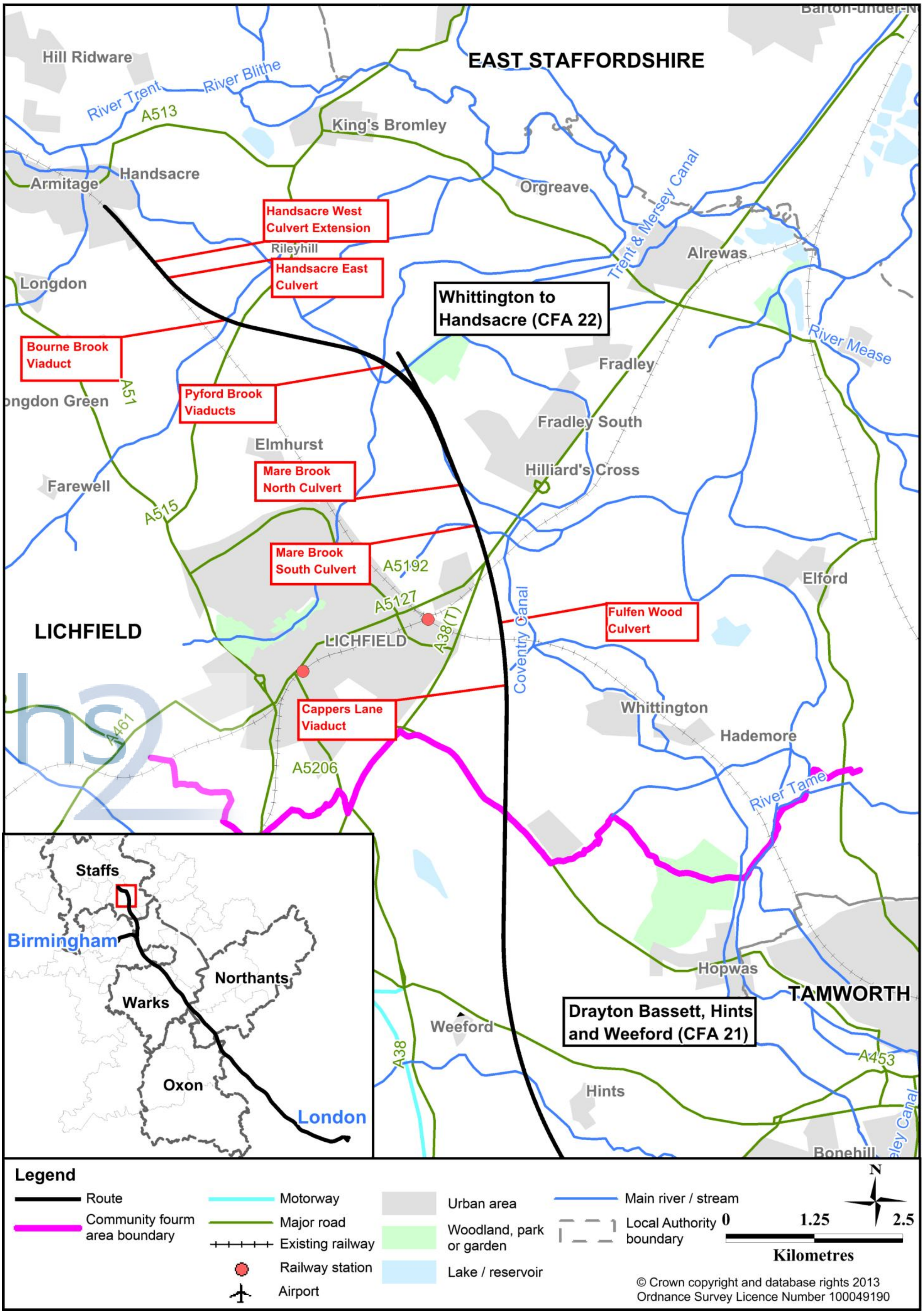
Table 1: River models at watercourse crossings

Crossing name	Watercourse identifier	Watercourse	Hydrology	Hydraulic modelling
Capper's Lane viaduct	SWC-CFA22-001 Volume 5: Map Book – Water resources, Map WR-05-062, G5	Ordinary Watercourse (tributary of Fisherwick Brook)	FEH Statistical	Two dimensional hydrodynamic
Fulfen Wood culvert	SWC-CFA22-003 Volume 5: Map Book – Water resources, Map WR-05-062, E6	Main River (Mare Brook)	Area scaling method	Two dimensional hydrodynamic
Mare Brook South culvert	SWC-CFA22-004 Volume 5: Map Book – Water resources, Map WR-05-063, I5	Ordinary Watercourse (tributary of Mare Brook)	FEH Statistical	Two dimensional hydrodynamic
Mare Brook North culvert	SWC-CFA22-006 Volume 5: Map Book – Water resources, Map WR-05-063, G5	Ordinary watercourse (tributary of Mare Brook)	ReFH	Two dimensional hydrodynamic
Pyford Brook viaduct	SWC-CFA22-010 Volume 5: Map Book – Water resources, Map WR-05-063, C7	Main River (Curborough Brook)	ReFH	Two dimensional hydrodynamic
Bourne Brook viaduct	SWC-CFA22-012 Volume 5: Map Book – Water resources, Map WR-05-064, D7	Ordinary Watercourse (Bourne Brook)	ReFH	Two dimensional hydrodynamic
Handsacre East culvert	SWC-CFA22-017 Volume 5: Map Book – Water resources, Map WR-05-065, H6	Ordinary watercourse (tributary of River Trent)	ReFH	One dimensional steady state
Handsacre West culvert extension	SWC-CFA22-018 Volume 5: Map Book – Water resources, Map WR-05-065, G6	Ordinary watercourse (tributary of River Trent)	ReFH	One dimensional steady state

2.1.2 It should be noted that the Curborough Brook is also known as Pyford Brook. The viaduct structure crossing this watercourse is named Pyford Brook viaduct.

2.1.3 A summary of the modelling of the culverts is provided in Section 0 of this report. The modelling, including details of the specific modelling methodologies, hydraulic constraints and any assumptions on each of the watercourse crossings, is described in detail for each of the viaduct structures from Sections 2.3 to 2.5.

Figure 1: Location plan



2.2 Culverts

2.2.1 One dimensional ISIS models were built for watercourses at Handsacre East culvert and Handsacre West culvert extension. Two dimensional TUFLOW models were built for watercourses at Fulfen Wood culvert, Mare Brook South culvert and Mare Brook North culvert. The models built for the baseline and proposed scheme scenarios used the general methodologies for one dimensional and two dimensional modelling as discussed in Section 1.3 of this report.

2.2.2 The methodologies applied for the hydrological assessments for structures Mare Brook South culvert, Mare Brook North culvert, Handsacre East culvert and Handsacre West culvert extension are provided in the FEH proformas in Section 0 of this report.

2.2.3 For the watercourse that is crossed by the Fulfen Wood culvert, the catchment does not appear to be correctly represented in the FEH CD-ROM due to the large developed areas in the upstream reaches. Potentially a large proportion of the catchment covers the developed area of Lichfield, as well as the rural area downstream of a culvert outlet prior to reaching the proposed crossing. The surface water drainage network to the culvert, on the watercourse crossed by the route at this location, is unknown and hence it not possible to determine the extent of Lichfield that would drain to this location. Therefore the manually derived catchment has been determined based on a conservative approach which resulted in a catchment area of 2.6km^2. The flow has been estimated using the area scaling method, taking a scaling factor of one (based on the other catchments for which ReFH was used to determine flows), which is considered conservative, for the 1 in 100 (1%) annual probability event with a 20% allowance for climate change. This method considers that the flow at this location is likely to be an overestimate, however has been considered suitable for this assessment given a conservative approach is preferable.

2.2.4 At the Mare Brook North culvert crossing, the route crosses the watercourse splitting its catchment into two, the western and eastern sub-catchments. The catchment flowing west of the route will be diverted south via the western watercourse up to a point where it then crosses the route by the Mare Brook North culvert. The catchment flowing east of the crossing will also be diverted south via the eastern watercourse which will rejoin the western watercourse at the Mare Brook North culvert crossing. The hydrological assessment for the watercourse at Mare Brook North culvert is described in Section 0 of this report. The total flow estimate for the catchment to Mare Brook North culvert was split with 46.5% of the flow in the eastern sub-catchment and 53.5% in the western sub-catchment. Therefore, the catchment flows were applied separately as two constant inflow boundaries to the hydraulic model, feeding into the eastern and western watercourses respectively. The watercourses were represented by GIS polylines (Z-lines) with elevations providing the same bed slope as the original watercourse. The route embankment was represented by GIS polygons with elevations (Z-Shape layers) and one dimensional culvert was added at the crossing (refer to Section 1.3.23 of this report for modelling details).

2.2.5 The structures adopted at the various culvert crossings along with their impacts on peak flood levels is summarised in Table 2. The structure dimensions of width (W), height (H) and length (L) in metres are also provided in this table.

Table 2: Modelled peak levels at culvert crossings

Structure	Watercourse identifier	Structure dimensions (WxHxL)	Flood event	Peak flood level		Change in flood level	Length of impact upstream reach[8]
				Baseline	Scheme		
Fulfen Wood culvert	SWC-CFA22-003	4m x 2m x 77m	1 in 20 (5%)	63.834mAOD	63.846mAOD	12mm	162m
			1 in 100 (1%) climate change	63.862mAOD	63.901mAOD	39mm	
			1 in 1000 (0.1%)	63.896mAOD	63.978mAOD	82mm	
Mare Brook South culvert	SWC-CFA22-004	2m x 1.5m x 70m	1 in 20 (5%)	64.136mAOD	64.129mAOD	-7mm	No impact
			1 in 100 (1%) climate change	64.152mAOD	64.146mAOD	-6mm	
			1 in 1000 (0.1%)	64.197mAOD	64.212mAOD	15mm	
Mare Brook North culvert	SWC-CFA22-006	2m x 1.5m x 79m	1 in 20 (5%)	64.531mAOD	64.473mAOD	-58mm	No impact
			1 in 100 (1%) climate change	64.553mAOD	64.480mAOD	-73mm	
			1 in 1000 (0.1%)	64.580mAOD	64.488mAOD	-92mm	
Handsacre East culvert	SWC-CFA22-017	2m x 1.5m x50m	1 in 20 (5%)	71.742mAOD	71.695mAOD	-47mm	No impact
			1 in 100 (1%) climate change	71.775mAOD	71.733mAOD	-42mm	
			1 in 1000 (0.1%)	71.806mAOD	71.775mAOD	-31mm	
Handsacre West culvert extension	SWC-CFA22-018	2m x 1.5m x40m	1 in 20 (5%)	72.253mAOD	72.175mAOD	-78mm	No impact
			1 in 100 (1%) climate change	72.315mAOD	72.238mAOD	-77mm	
			1 in 1000 (0.1%)	72.379mAOD	72.315mAOD	-64mm	

2.2.6 For Fulfen Wood culvert, there is an increase in peak levels of up to 39mm for the 1 in 100 (1%) annual probability with an allowance for climate change event. Increases of peak levels of greater than 10mm are limited to 162m upstream of the crossing. A replacement flood storage area has been identified. This has been modelled and the results show that it will mitigate the increase in peak levels.

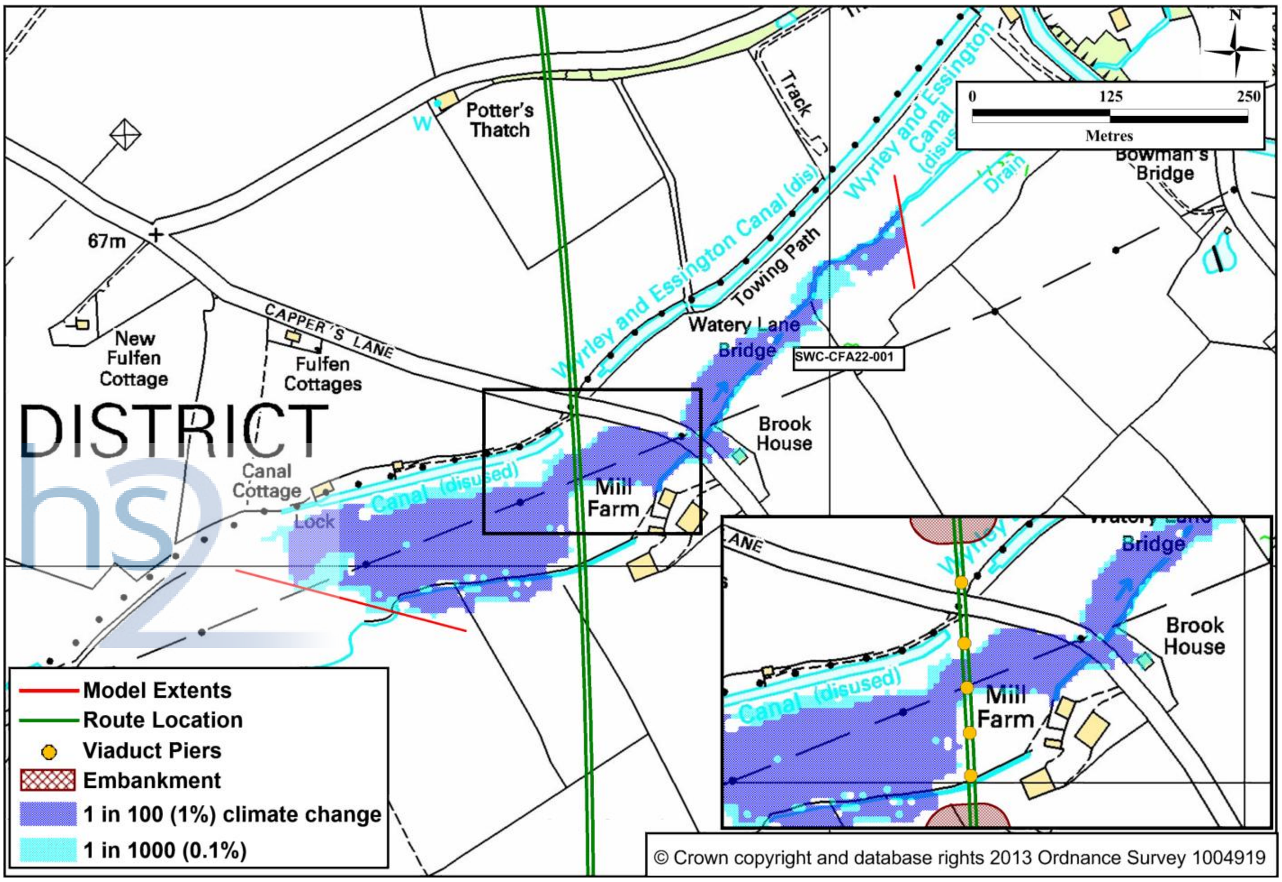
[8] Length of reach upstream of the scheme along which flood levels during the 1 in 100 (1%) annual probability with an allowance for climate change event are greater than 10mm.

2.2.7 The culverts Mare Brook north culvert, Mare Brook South culvert, Handsacre East culvert and Handsacre West culvert extension showed decreases in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. This showed that the culverts modelled provided flow capacity in excess of that required to convey flood flows and hence results in a reduction in peak levels. Therefore, these culverts do not increase flood risk. It should be noted that changes in peak levels are localised at the structure with minimal changes elsewhere on the watercourse.

2.3 Cappers Lane viaduct

2.3.1 The crossing will consist of the viaduct structure of 210m width on the watercourse SWC-CFA22-001 (Volume 5: Map Book – Water resources, Map WR-05-062, G5). This watercourse flows from west of the crossing and continues east within the model extents shown in Figure 2.

Figure 2: Crossing location plan and flood extents for Capper's Lane viaduct



Hydrology

2.3.2 The river inflow hydrology was defined using the FEH Statistical method for permeable catchments. The peak flow from the hydrology calculation was used as a constant inflow into the model. This was to ensure that the defined peak flow across the route was maintained. The details of the hydrological assessment are provided in the FEH proformas within Section 0 of this report. The flows into the model are summarised in Table 3.

Table 3: Hydrology results: model inflows to Capper's Lane viaduct

Watercourse identifier	Environment Agency Flood Zone	1 in 20 (5%) flow	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA22-001	3	$0.92m^3/s$	$1.22m^3/s$	$3.32m^3/s$	Viaduct

Hydraulics

2.3.3 The TUFLOW model was built on a 5m cell resolution. The two dimensional domain covered the floodplain of the watercourse, the extents of which were defined by the available LiDAR data. The inflow to the watercourse was applied upstream using a boundary condition polyline layer, linking it to a steady state flow time series within a boundary condition database. The downstream boundary was an HQ polyline layer based on the slope of the floodplain at that location; which was 0.001 in this case. The resulting baseline model was run at a two second timestep for the duration of 15 hours.

2.3.4 Two flood levels were identified for each of the annual probability flood events as shown in the cross section figure. This is due to the fact that the watercourse modelled runs along a steep verge at one side, which when overtopped flood water flows down and onto the floodplain next to the disused Wyrley and Essington Canal. The floodplain peak levels have been quoted for this crossing as the major proportion of the flood flows occur along the floodplain.

2.3.5 The viaduct structure was modelled by adding FC shape layers which represented the piers. The suggested pier dimension was 2m, however for simplicity a percentage blockage of 50% and a form loss coefficient was added to the cells in the location of the piers. The embankments on either side of the viaduct were modelled as Z-polygon layers. The soffit levels were not added into the model because the vertical alignment of the route at this location is significantly above the 1 in 1000 (0.1%) annual probability modelled peak flood levels.

2.3.6 There are three key hydraulic constraints to this model.

2.3.7 Firstly, it was assumed that the Capper's Lane embankment just downstream of the crossing will have a significant impact on flood risk. This was based on the LiDAR DTM and its close proximity to the crossing. There was no available information on the type and dimensions of the Capper's Lane culvert structure and hence it was not modelled explicitly. A Z-polyline layer was added to represent the flow route through the Capper's Lane culvert structure. The elevations were set at the channel bed levels and the structure width was set to the width of the channel. The model results reported later show that the Proposed Scheme has minimal impact on flood risk which is localised to the crossing. The impact of the Proposed Scheme on flood risk would not be impacted by the hydraulic impacts of Capper's Lane embankment. The vertical alignment of the route and the soffit levels would be sufficient higher than the 1 in 1000 (0.1%) annual probability modelled peak flood levels. Therefore, any uncertainty in the Capper's Lane culvert structure would not have an impact of the design of the Proposed Scheme.

2.3.8 Secondly, the Coventry Canal downstream would potentially have an impact on the hydraulics of the watercourse. However, the downstream impact of the Coventry

Canal and associated culvert underneath was not modelled due to the lack of culvert dimensions. However, it is unlikely to have a significant impact on flood levels at the crossing, as the Capper's Lane embankment immediately downstream of the HS2 crossing (and upstream of the Coventry Canal) would have a predominant impact.

2.3.9 Thirdly, the watercourse is located on high ground with the left floodplain sloping down to the disused Wyrley and Essington Canal. Any overtopping on the left bank of the watercourse would divert floodwaters down into the left floodplain.

2.3.10 The baseline floodplain width at the crossing is 88m for a 1 in 100 (1%) annual probability with an allowance for climate change event. The cross section with peak flood levels is shown in Figure 3. The modelled peak levels along with scheme impacts is summarised in Table 4. The baseline peak velocities and scheme impacts for the 1 in 100 (1%) annual probability with an allowance for climate change event is also provided in Figure 4.

Figure 3: Cross section with flood levels for Capper's Lane viaduct

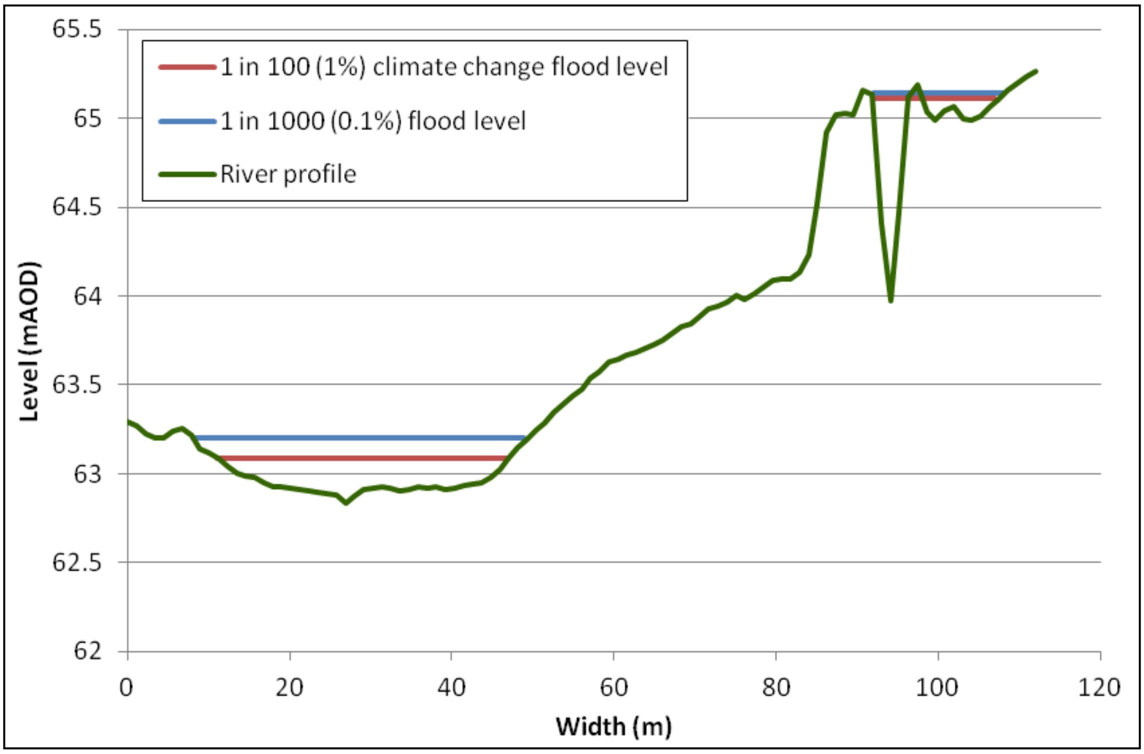
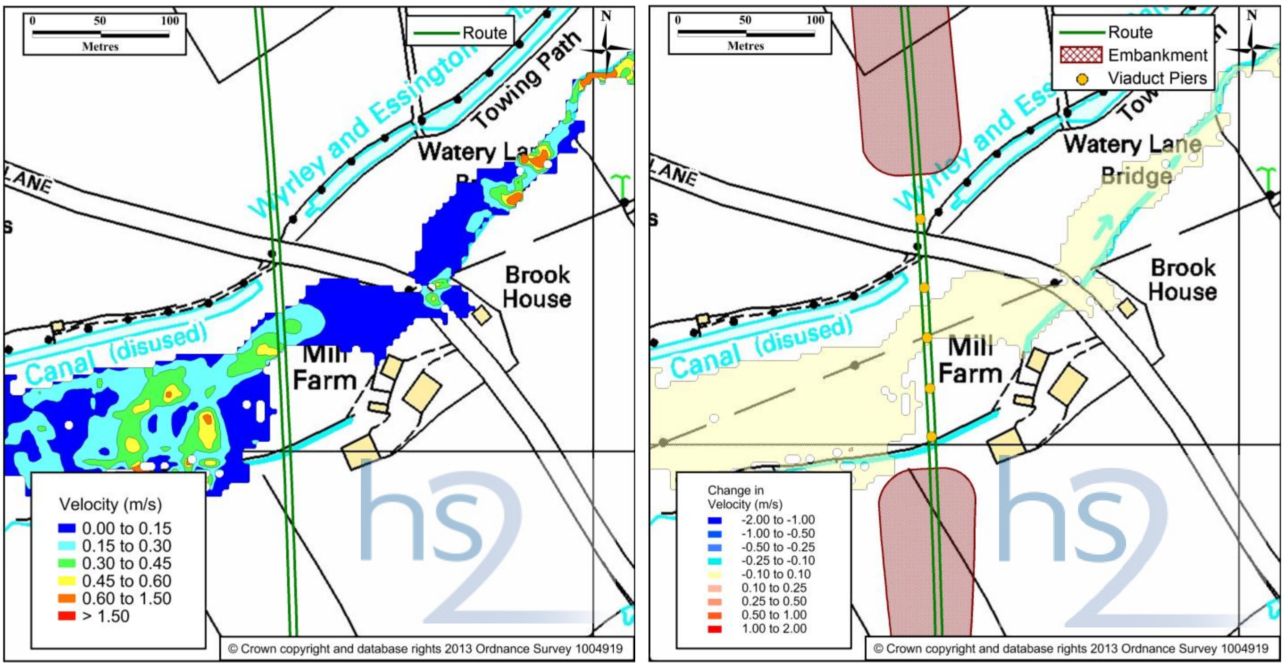


Table 4: Modelled peak levels for Capper's Lane viaduct

Flood event	Peak flood level		Change in flood level
	Baseline	Scheme	
1 in 20 (5%)	63.067mAOD	63.068mAOD	1mm
1 in 100 (1%) climate change	63.090mAOD	63.090mAOD	0mm
1 in 1000 (0.1%)	63.204mAOD	63.207mAOD	3mm

Figure 4: Baseline peak velocity contours and scheme impact on velocities for 1 in 100 (1%) climate change event at Capper's Lane viaduct



Sensitivity assessment

2.3.11 Sensitivity assessment was carried out by adding 20% to the 1 in 100 (1%) annual probability with an allowance for climate change and 1 in 1000 (0.1%) annual probability events. Models were run for both the baseline and scheme scenarios. The peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event increased by up to 17mm with an increase in flood extent of 6%. No additional receptors have been affected as a result.

2.3.12 These changes were considered minimal and hence the impact of the scheme on flood risk will still be valid with these sensitivity changes.

Conclusions

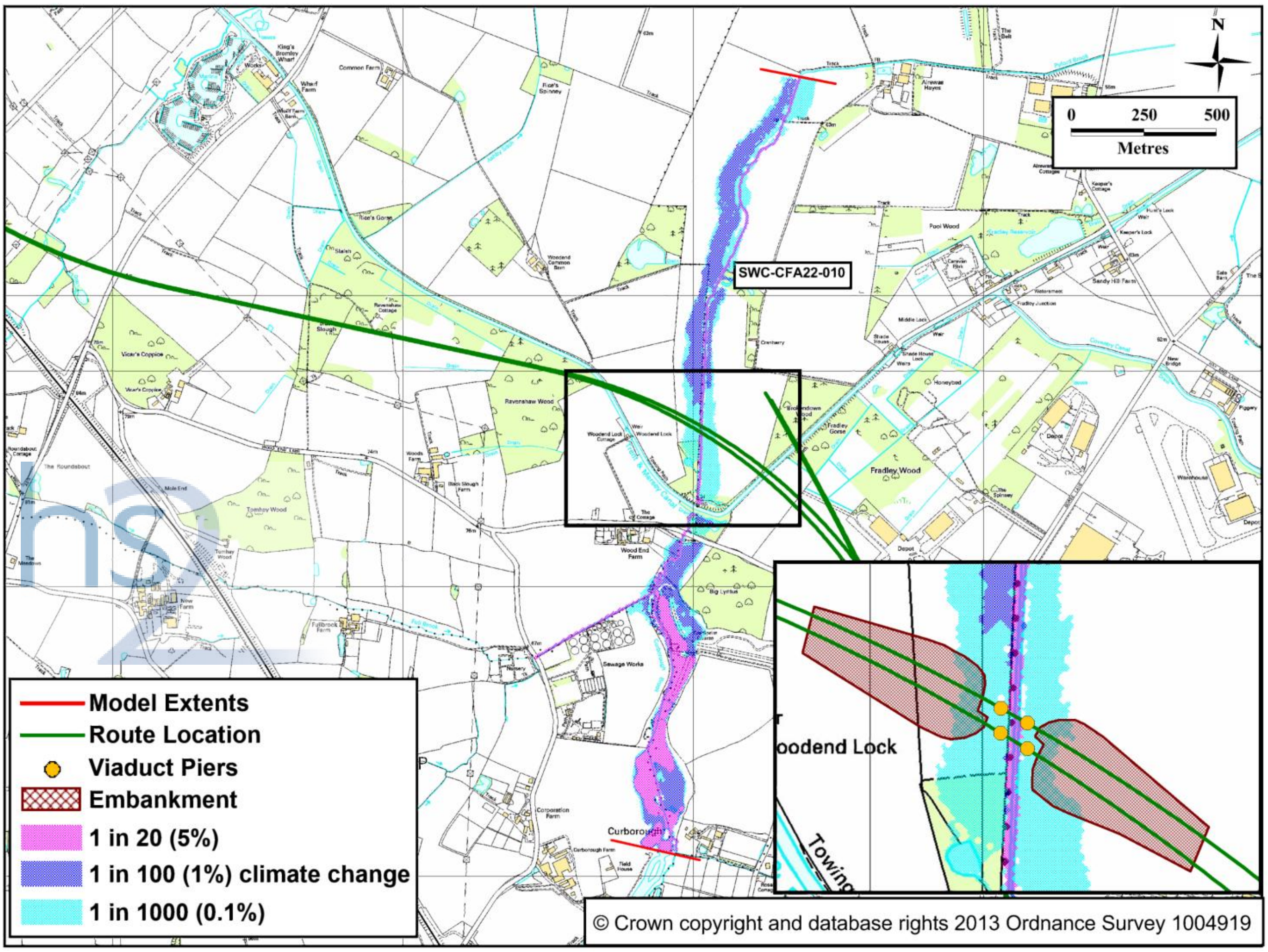
2.3.13 The scheme showed minimal impacts on the peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. Therefore, the viaduct structure will not have any impact on flood risk.

2.3.14 There are localised increases of velocities up to 0.07m/s at the crossing and minimal changes elsewhere.

2.4 Pyford Brook viaduct

2.4.1 The crossing will consist of a viaduct structure of 63m width on the Curborough Brook, SWC-CFA22-010 (Volume 5: Map Book – Water resources, Map WR-05-063, C7). The watercourse flows from south of the crossing and continues as shown in Figure 5.

Figure 5: Crossing location plan and flood extents for Pyford Brook viaduct



Hydrology

2.4.2 The hydrological inflow was calculated using the ReFH method. The catchment area was determined from the FEH CD-ROM. Catchment descriptors were extracted from the FEH CD-ROM and updated for urban expansion. The critical storm duration was calculated at the location of the crossing. Flows were then calculated based on these catchment descriptors as no suitable local donor station was identified. The FEH proforma for this watercourse is provided in Section 0 of this report.

Table 5: Hydrology results: model inflows to Pyford Brook

Watercourse identifier	Environment Agency Flood Zone	1 in 20 (5%) flow	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA22-010	3	4.71m^3/s	8.46m^3/s	15.51m^3/s	Viaduct

Hydraulics

2.4.3 A TUFLOW model has been constructed and built with a 5m cell resolution. The topography of the model is based upon 5m resolution LiDAR data. Around the location of the route, more detailed 0.2m resolution LiDAR data has been utilised. A Manning's n value of 0.05 has been used to define the floodplain and a value of 0.03 has been used to define the watercourse. These values have been selected based on a desk-based study.

2.4.4 Watercourses within the modelled extent have been defined using the TUFLOW flow constriction and storage reduction factor functions. These allow for the capacity of the channel to be reduced and not limited to the cell resolution of the model. Bed levels and the width of watercourses have been estimated from the LiDAR DTM.

2.4.5 An HQ boundary has been applied to the downstream extent of the model and has been automatically generated by TUFLOW based on an assumed floodplain gradient of 0.003. The gradient has been measured from the LiDAR DTM along the channel bed at this location.

2.4.6 The Proposed Scheme was modelled by representing the embankment as a Z-shape layer with a gap representing the viaduct width. It should be noted that the model scenario reported here represents an early design iteration of the viaduct with a width of 95m which is different to the 63m width of the Proposed Scheme. The results showed that the there was no out of bank flow during the 1 in 20 (5%) annual probability and 1 in 100 (1%) annual probability with an allowance for climate change events, therefore it was not necessary to reassess the impact of the narrower viaduct.

2.4.7 For the 1 in 1000 (0.1%) annual probability event, the peak levels will approximately 8m below the soffit level of the proposed viaduct. Therefore, the model outputs reported here are suitable to confirm the impacts of the Proposed Scheme on flood risk.

2.4.8 There are three key hydraulic constraints to this model.

2.4.9 Firstly, the Curborough Brook flows under Wood End Lane approximately 200m upstream of the proposed HS2 crossing. This structure is currently not modelled and is represented only by the watercourse flow constriction and storage reduction functions. This structure has currently been modelled with no soffit or deck level. The road is also slightly raised and acts as an embankment retaining flood water.

2.4.10 Secondly, the watercourse then flows under the Trent and Mersey Canal approximately 100m upstream of the crossing. This structure has been modelled in one dimension with the width of the structure assumed to be equal to the width of the watercourse. The soffit level was estimated by calculating the depth between the crest of the road embankment and the bed level of the drain, minus the clearance above the culvert. The canal embankment is raised and retains river floodplain flow.

2.4.11 Thirdly, due to the desk-based nature of this study the dimensions of these structures are not known and therefore the width of the structures has been assumed to be the same size as the channel. The structures have been represented in one dimension and approximate channel widths and invert levels have been taken from LiDAR data.

2.4.12 The baseline floodplain width at the crossing is 13m for a 1 in 100 (1%) annual probability with an allowance for climate change event. The cross section with peak flood levels is shown in Figure 6. The modelled peak levels along with scheme impacts is summarised in Table 6. The baseline peak velocities and scheme impacts for the 1 in 100 (1%) annual probability with an allowance for climate change event is also provided in Figure 7.

Figure 6: Cross section with flood levels at Pyford Brook viaduct

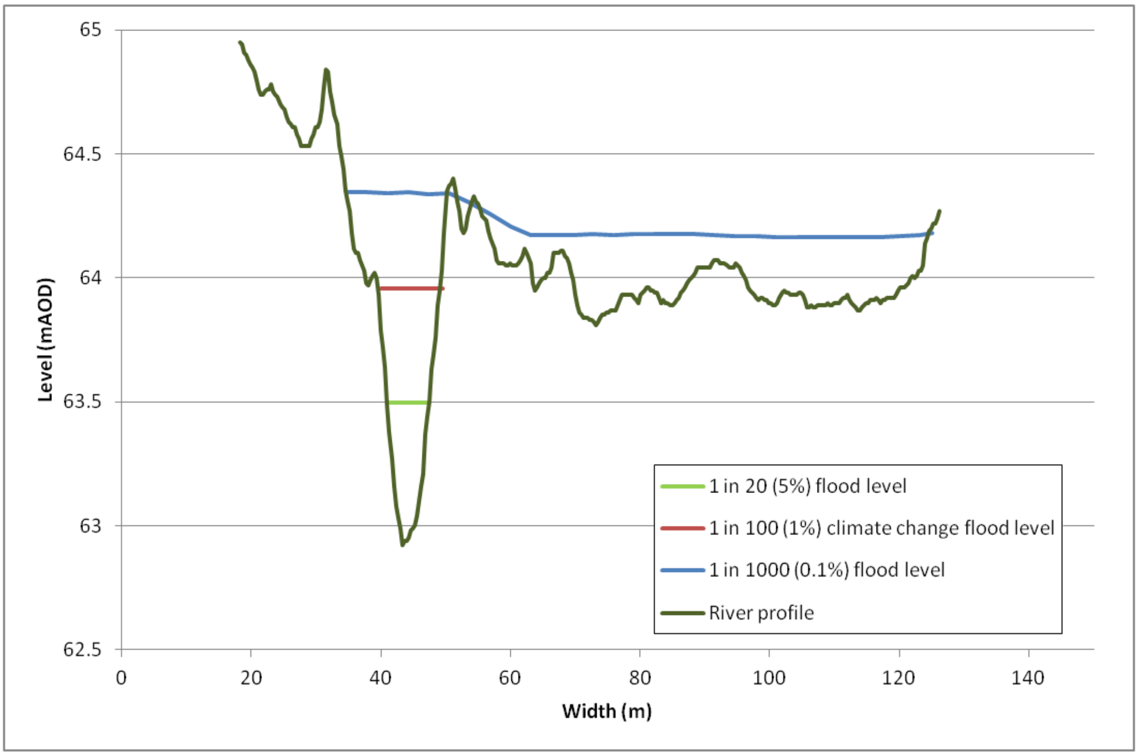
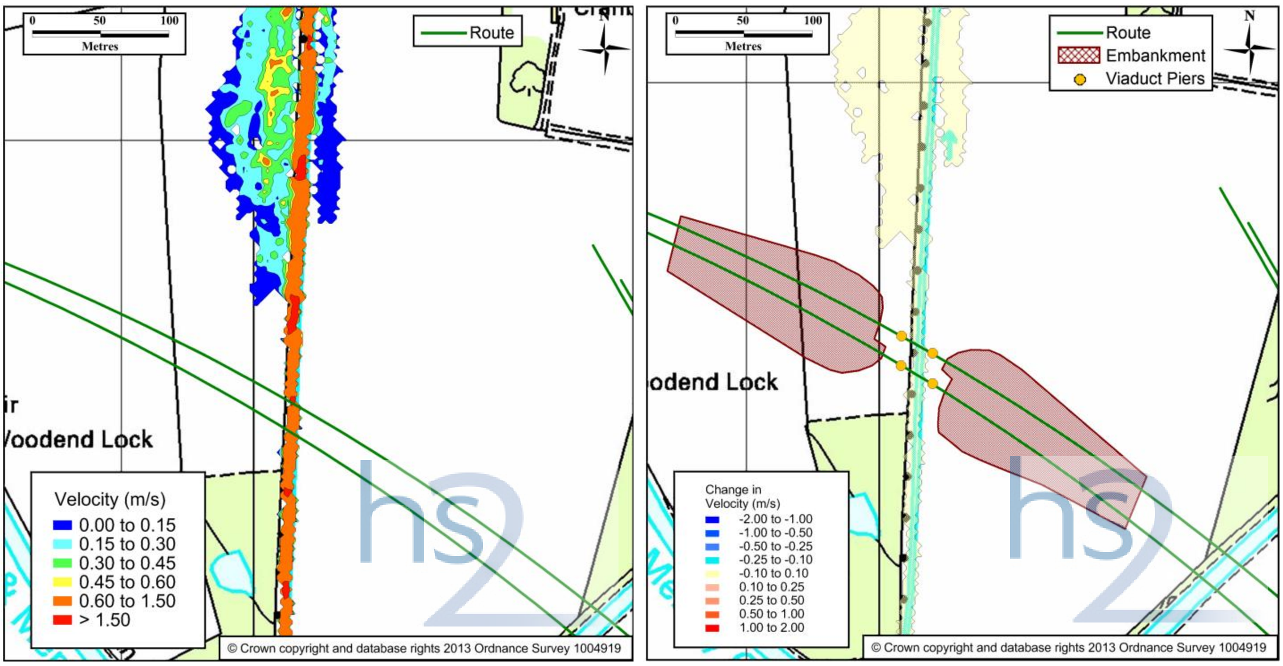


Table 6: Modelled peak levels for Pyford Brook viaduct

Flood event	Peak flood level		Change in flood level
	Baseline	Scheme	
1 in 20 (5%)	63.500mAOD	63.500mAOD	0mm
1 in 100(1%) climate change	63.959mAOD	63.959mAOD	0mm
1 in 1000 (0.1%)	64.202mAOD	64.210mAOD	8mm

Figure 7: Baseline peak velocity contours and scheme impacts on velocities for the 1 in 100 (1%) climate change event at Pyford viaduct



Sensitivity assessment

2.4.13 Sensitivity assessment was undertaken on the inflows by increasing and decreasing flows by 20% on the 1 in 100 (1%) annual probability with an allowance for climate change event. A 20% increase in flows causes up to a 170mm increase in channel peak levels and showed inundation of the floodplain at the crossing which did not show flooding before. The peak levels with the sensitivity allowance are still well below the soffit level, providing the necessary clearance of 600mm. A 20% decrease in flows causes up to a 190mm decrease in channel peak levels.

2.4.14 The increase in inflows showed an increase in the flood extents of up to 41% with greatest increases seen at the crossing. However, no additional receptors apart from agricultural land were affected. Therefore, the impact of the scheme on flood risk will still be valid with these sensitivity changes.

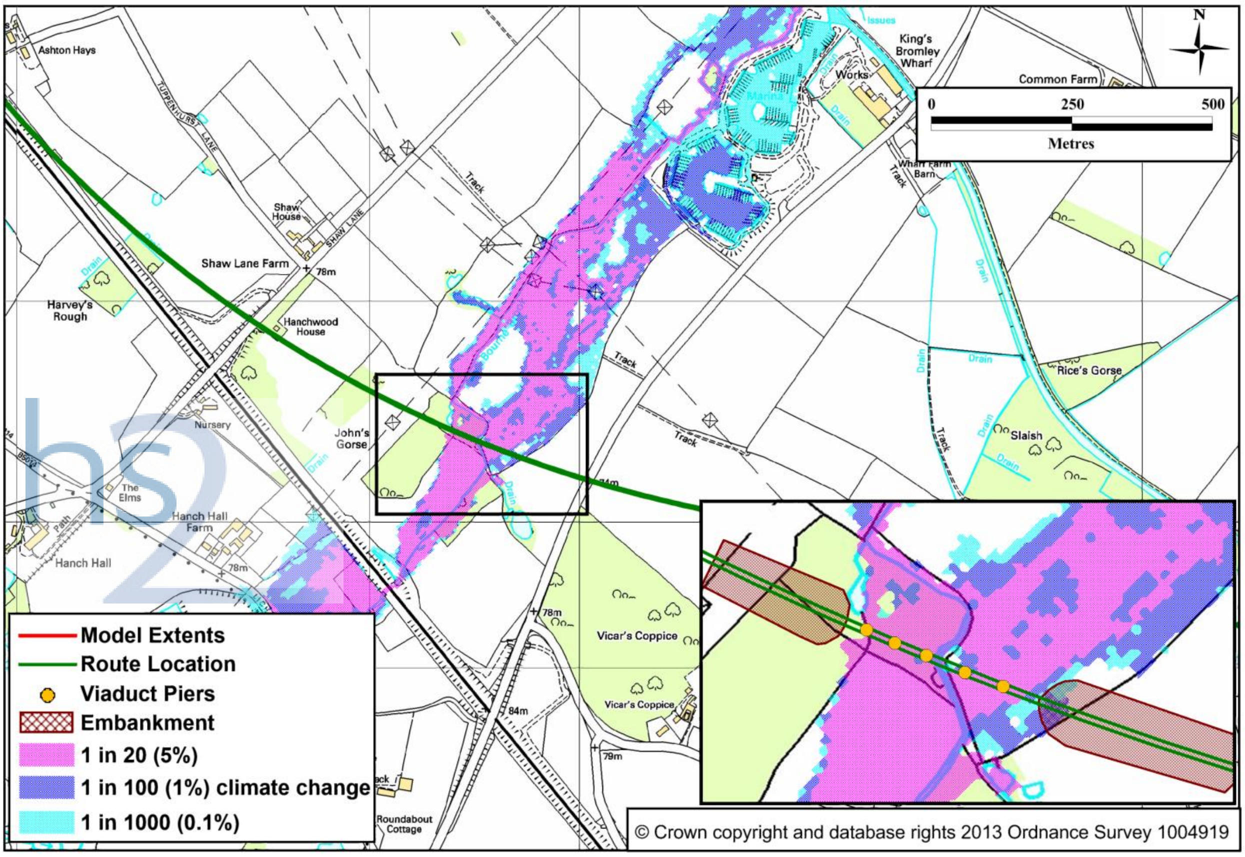
Conclusions

2.4.15 The scheme did not show any increase in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. Therefore, the viaduct structure will not have any impact on flood risk. There is no change in velocities due to the structure.

2.5 Bourne Brook Viaduct

2.5.1 The crossing will consist of a viaduct structure of 124m width on Bourne Brook SWC-CFA22-012 (Volume 5: Map Book – Water resources, Map WR-05-064, D7). The watercourse flows from south-west of the crossing and continues north-east as shown in Figure 8.

Figure 8: Crossing location plan and flood extents for Bourne Brook viaduct



Hydrology

2.5.2 The hydrological inflow was calculated using the ReFH method. The catchment area was inferred from the LiDAR DTM. Catchment descriptors were extracted from the FEH CD-ROM and updated for urban expansion. The catchment area is less than 1km^2 hence, the catchment area and drainage path length was calculated and other catchment descriptors were used from an adjacent small catchment following a sensibility check. The critical storm duration was calculated for the catchment at the location of the crossing. Flows were then calculated based on the above described catchment descriptors as no suitable local donor station was identified. The FEH proforma for this watercourse is provided in Section 0 of this report. The flows used in the model are summarised in Table 7.

Table 7: Hydrology results: model inflows for Bourne Brook viaduct

Watercourse identifier	Environment Agency Flood Zone	1 in 20 (5%) flow	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA22-012	3	7.33m^3/s	12.73m^3/s	19.82m^3/s	Viaduct

Hydraulics

2.5.3 A TUFLOW model has been constructed and built with a 5m cell resolution. The topography of the model is based upon 5m resolution LiDAR data. Around the location of the crossing, more detailed 0.2m resolution LiDAR data has been utilised. A Manning's n value of 0.05 has been used to define the floodplain and a value of 0.03 has been used to define the watercourse. These values have been selected based on a desk-based study.

2.5.4 Watercourses within the modelled extent have been defined using the TUFLOW flow constriction and storage reduction factor functions. These allow for the capacity of the channel to be reduced and not limited to the cell resolution of the model. Bed levels and the width of watercourses have been estimated from the LiDAR DTM.

2.5.5 An HQ boundary has been applied to the downstream extent of the model and has been automatically generated by TUFLOW based on an assumed floodplain gradient of 0.004. The gradient has been measured from the LiDAR DTM along the channel bed at this location.

2.5.6 There are two key hydraulic constraints to this model.

2.5.7 Firstly, the Bourne Brook flows under Lichfield Road approximately 500m upstream of the crossing and under the existing railway embankment approximately 300m upstream. The structures are currently only represented by the watercourse flow constriction and storage reduction factor functions. The railway embankment, represented in the LiDAR, retains a large amount of floodwater.

2.5.8 Secondly, Hanch Reservoir which is located approximately 700m upstream of the crossing; the reservoir is modelled as full at 79mAOD in the model. This is a conservative assumption and assumes the reservoir provides no additional storage in a flood event.

2.5.9 The baseline floodplain width at the crossing is 162m for a 1 in 100 (1%) annual probability with an allowance for climate change event. The cross section with peak

flood levels is shown in Figure 9. The modelled peak levels along with scheme impacts is summarised in Table 8. The baseline peak velocities and scheme impacts for the 1 in 100 (1%) annual probability with an allowance for climate change event is also provided in Figure 10.

Figure 9: Cross section with flood levels for Bourne Brook viaduct

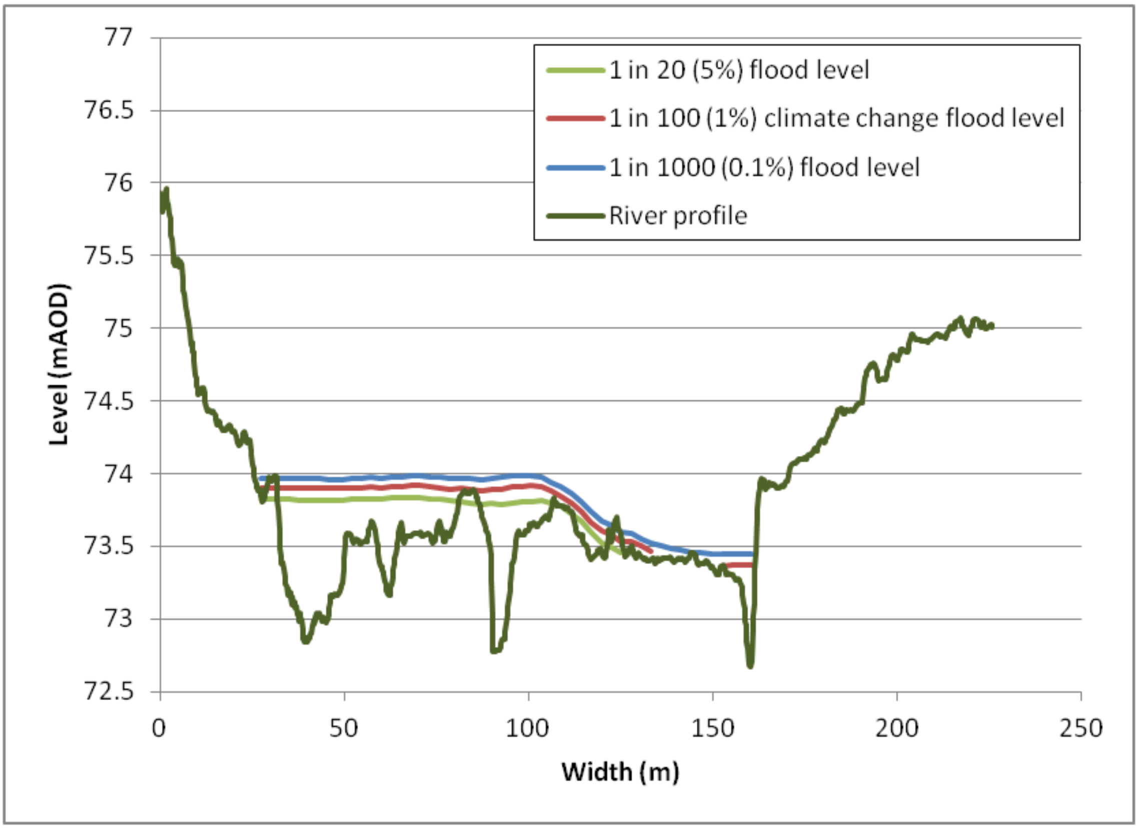
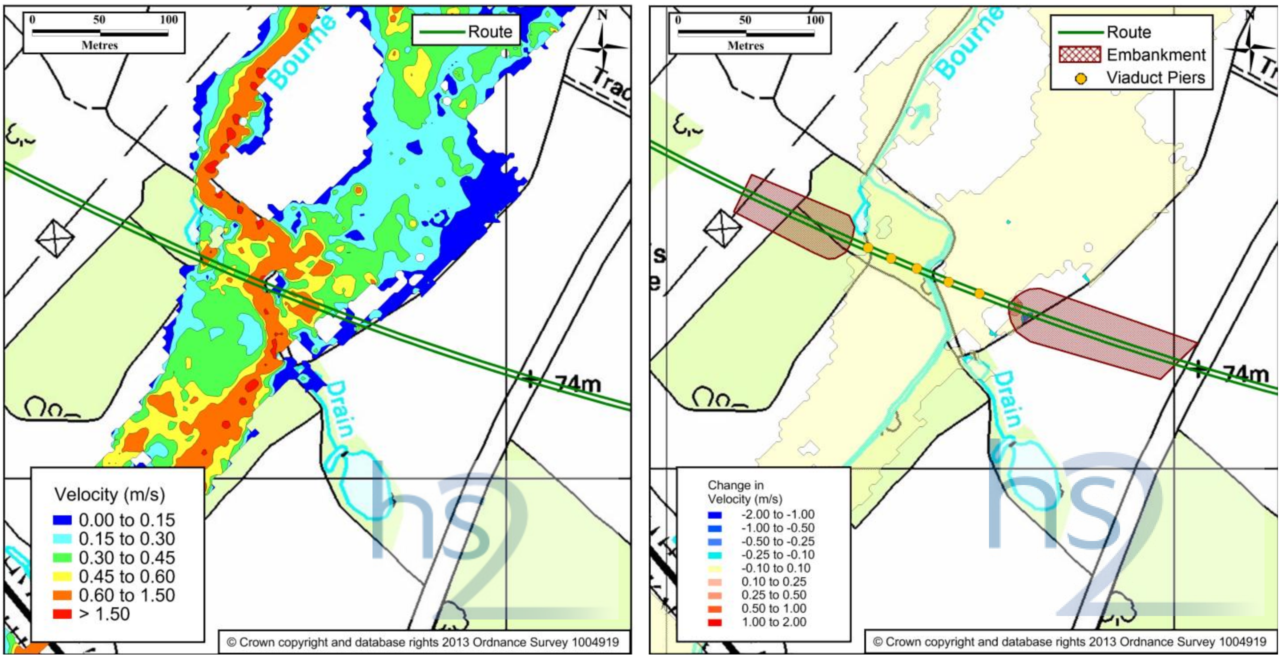


Table 8: Modelled peak levels for Bourne Brook viaduct

Flood event	Peak flood level		Change in flood level
	Baseline	Scheme	
1 in 20 (5%)	73.790mAOD	73.790mAOD	0mm
1 in 100 (1%) climate change	73.802mAOD	73.793mAOD	-9mm
1 in 1000 (0.1%)	73.826mAOD	73.833mAOD	7mm

Figure 10: Baseline peak velocity contours and scheme impacts on velocities for 1 in 100 (1%) climate change at Bourne Brook viaduct



Sensitivity assessment

2.5.10 Sensitivity assessment was undertaken on the inflows by increasing and decreasing flows by 20% on the 1 in 100 (1%) annual probability with an allowance for climate change event. A 20% increase in flows causes up to a 30mm increase in channel peak levels and a 20mm increase in floodplain peak levels. The peak levels with the sensitivity allowance are still well below the soffit level, providing the necessary clearance of 600mm. A 20% decrease in flows causes up to a 20mm decrease in channel peak levels and a 30mm decrease in floodplain peak levels.

2.5.11 The increase in inflows resulted in an increase in flood extents of 15% mostly downstream of the crossing. However, no additional receptors apart from agricultural land were affected. Therefore, the impact of the scheme on flood risk will still be valid with these sensitivity changes.

Conclusions

2.5.12 The scheme showed no increase in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event and hence no increase in flood risk. There were minimal changes in velocities due to the viaduct structure.

3 FEH proformas

3.1 Overview

3.1.1 This section provides the FEH proformas for the hydrological calculations of the various watercourses for which there was no existing hydrology available.

3.1.2 The FEH proformas are based on the Environment Agency supporting document to the flood estimation guidelines[4].

3.1.3 The FEH proformas provided here are for the watercourses at the Capper's Lane viaduct (SWC-CFA22-001), Mare Brook South culvert (SWC-CFA22-004), Mare Brook North culvert (SWC-CFA22-006), Pyford Brook viaduct (SWC-CFA22-010), Bourne Brook viaduct (SWC-CFA22-012), Handsacre East culvert (SWC-CFA22-017) and Handsacre West culvert extension (SWC-CFA22-018).

3.1.4 In Section 3.2 of this report, derivation of flows using the ReFH method for crossing Mare Brook north culvert are presented, with the derivation of scaling factors for the 1 in 1000 (0.1%) annual probability flows for crossings Capper's Lane viaduct and Mare Brook south culvert.

3.1.5 Section 3.3 of this report presents the derivation of flows using the FEH Statistical method for the two highly permeable catchments which drain to crossings Capper's Lane viaduct and Mare Brook south culvert.

3.1.6 Section 3.4 of this report details the derivation of flows for Pyford Brook viaduct, Bourne Brook viaduct, Handsacre East culvert and Handsacre West culvert extension.

3.2 Capper's Lane viaduct, Mare Brook South culvert and Mare Brook North culvert

Method statement

Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: Purpose of study Approx. no. of flood estimates required Peak flows or hydrographs? Range of return periods and locations Approx. time available	This proforma outlines the hydrological calculations carried out for the assessment of flood risk for the Proposed Scheme. As part of the Proposed Scheme, two of the watercourses will require culvert structures under the rail line and hence it must be ensured that the culvert would be of sufficient capacity. The other watercourse at Capper's Lane viaduct has a viaduct structure due to additional floodplain flow. It is vital at this stage that the proposed structures are not under designed and hence conservative flows are necessary in line with current requirements of the Proposed Scheme. At a later stage, if a more in-depth assessment determines lower flow, and hence smaller structures would have sufficient capacity, this is acceptable. This particular assessment outlines the derivation of flows at Capper's Lane viaduct (SWC-CFA22-001), Mare Brook south culvert (SWC-CFA22-004) and Mare Brook north culvert (SWC-CFA22-006) for the 1 in 20 (5%) annual probability, 1 in 100 (1%) annual probability, 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability.

Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The three crossings have separate catchments which are rural and ranging from low permeability to permeable catchments. The catchments range in size of $0.58km^2$ to $14.83km^2$.

Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	No. Only method implemented at this stage is ReFH and hence HiFlows data is not utilised.

Gauging stations (flow or level)

3.2.1 Gauging stations at the sites of flood estimates or nearby at potential donor sites.

3.2.2 Local donor sites have been sought however in most cases the catchment area of the subject catchment was found to be significantly smaller than that of any potential local donor.

Watercourse	Station name	Gauging authority number	National River Flow Archive number (used in FEH)	Grid reference	Catchment area (km²)	Type (rated/ ultrasonic/ level	Start and end of flow record
N/A							

Data available at each flow gauging station

Station name	Start and end of data in HiFlows UK	Update for this study?	Suitable for QMED	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers
N/A						
Give link/reference to any further data quality checks carried out						

Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
N/A			
Give link/reference to any rating reviews carried out			

Other data available and how it has been obtained

Type of data	Data relevant to this study	Data available?	Source of data and licence reference if from Environment Agency	Date obtained	Details
Check flow gaugings (if planned to review ratings)	No				

Type of data	Data relevant to this study	Data available?	Source of data and licence reference if from Environment Agency	Date obtained	Details
Historic flood data – give link to historic review if carried out.	No				
Flow data for events	No				
Rainfall data for events	No				
Potential evaporation data	No				
Results from previous studies	No				
Other data or information (e.g. groundwater, tides)	No				

Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	ReFH has been utilised for this assessment, as a quick method for determining flows, given the high number of locations requiring flood estimates within the northern area of the Proposed Scheme. At the beginning of the modelling study this method was specifically aimed at determining at which locations the proposed culvert or bridge would have sufficient capacity for flood flows, and hence whether the proposed routes design requires mitigation.
Outline the conceptual model, addressing questions such as: **Where are the main sites of interest?** **What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides …)** **Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir?** **Is there a need to consider temporary debris dams that could collapse?**	The main sites of interest are at the crossing locations and hence are the points at which flow has been derived. Each point at which flow has been derived has been named in accordance with the associated watercourse identifier. At this stage it is considered that peak flows are likely to be the main cause of flooding, following development, due to the potentially constricting culvert or bridge. As part of this assessment it is not deemed necessary to consider the risk of a temporary dam collapse.
Any unusual catchment features to take into account? **e.g.** **highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20%** **highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments** **pumped watercourse – consider lowland catchment version of rainfall-runoff method** **major reservoir influence (FARL<0.90) – consider flood routing** **extensive floodplain storage – consider choice of method carefully**	The catchments for Capper's Lane viaduct (SWC-CFA22-001) and Mare Brook south culvert (SWC-CFA22-004) are classed as highly permeable, with BFIHOSTs of 0.688 and 0.751 and hence ReFH would not normally be the initial method of choice. However, for the purposes of deriving scaling factors for 1 in 1000 (0.1%) annual probability flows, the ReFH assessment has been included with this proforma. All catchments have FARL>0.9 and is not highly urbanised.

Initial choice of method(s) and reasons **Will the catchment be split into subcatchments? If so, how?**	ReFH has been used as the only method for determining flows at Mare Brook north culvert (SWC-CFA22-006). As noted above for the purposes of deriving scaling factors for 1 in 1000 (0.1%) annual probability flows, the ReFH assessment has been included with this proforma for the permeable catchments that drain to crossings Capper's Lane viaduct (SWC-CFA22-001) and Mare Brook south culvert (SWC-CFA22-004). For the purposes of this assessment it was assumed that the catchment descriptors and boundaries as output from the FEH CD-ROM are accurate and hence no manual adjustment was carried out.
Software to be used (with version numbers)	FEH CD-ROM v3.0[9] ISIS Free 3.3

Summary of subject sites

Site code (taken from watercourse identifier)	Watercourse	Site	Easting	Northing	Catchment area on FEH CD-ROM (km^2)	Catchment area if altered
SWC-CFA22-001	Ordinary Watercourse (tributary of Fisherwick Brook)	Capper's Lane viaduct	414770	308990	14.83	Not altered
SWC-CFA22-004	Ordinary Watercourse (tributary of Mare Brook)	Mare Brook South culvert	414360	311260	1.77	Not altered
SWC-CFA22-006	Ordinary Watercourse (tributary of Mare Brook)	Mare Brook North culvert	414180	311840	0.58	Not altered
Reasons for choosing above locations		Locations the route is proposed to cross the respective watercourses.				

Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT 2000	FPEXT
SWC-CFA22-001	0.908	0.31	0.862	3.96	31.3	670	16.55	0.040	0.064
SWC-CFA22-004	1.000	0.31	0.688	1.26	22.9	664	25.73	0.108	0.095
SWC-CFA22-006	1.000	0.31	0.605	0.56	8.8	658	29.68	0.000	0.095

[9] FEH CD-ROM v3.0 © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.

Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	Catchment boundaries were not checked, it was assumed that catchment boundaries as shown on the FEH CD-ROM were accurate. Where detailed assessment is required at a later stage, it is recommended that catchment boundaries are fully checked. This may result in different flows than those outlined within this proforma.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	No further checking of catchment descriptors was carried out.
Source of URBEXT	URBEXT1990
Method for updating of URBEXT	CPRE formula from FEH Volume 4

Revitalised flood hydrograph (ReFH) method

Parameters for ReFH model

3.2.3 Note: If parameters are estimated from catchment descriptors, they are easily reproducible so it is not essential to enter them in the table.

Site code	Method OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp (hours) Time to peak	Cmax (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
SWC-CFA22-001	CD	4.28	687	52	2.095
SWC-CFA22-004	CD	1.90	554	31	1.643
SWC-CFA22-006	CD	2.15	491	33	1.430
Brief description of any flood event analysis carried out (further details should be given below or in a project report)			None at this stage of the assessment.		

Note: only the catchments which are represented on the FEH CD-ROM have been included in the table above.

Design events for ReFH method

Site Code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
SWC-CFA22-001	Rural	Winter	7.1	0.952
SWC-CFA22-004	Rural	Winter	3.1	0.968
SWC-CFA22-006	Rural	Winter	3.5	0.979
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?			Storm durations will not be altered during the next stage of the hydraulic modelling.	

Flood estimates from the ReFH method

Site code	Flood peak (m3/s) for the following flood events				Scaling factor ratio of 1 in 1000 (0.1%) flow to the 1 in 100 (1%) flow
	1 in 20 (5%)	1 in 100 (1%)	1 in 100 (1%) climate change[10]	1 in 1000 (0.1%)	
SWC-CFA22-001[11]	0.43	1.00	1.20	3.28	3.28
SWC-CFA22-004[11]	0.55	0.84	1.01	1.73	2.05
SWC-CFA22-006	0.25	0.37	0.44	0.72	1.94

Discussion and summary of results

Comparison of results from different methods

3.2.4 This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

Site code	Ratio of peak flow to FEH Statistical peak					
	1 in 2 (50%)			1 in 100 (1%)		
	ReFH	Other method	Other method	ReFH	Other method	Other method
	N/A			N/A		

Final choice method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	ReFH has been used as the only method for determining flows at Mare Brook north culvert (SWC-CFA22-006). For the purposes of deriving scaling factors for 1 in 1000 (0.1%) annual probability flows, the ReFH assessment has been included with this proforma for the permeable catchments that drain to crossings Capper's Lane viaduct (SWC-CFA22-001) and Mare Brook south culvert (SWC-CFA22-004).

Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	The FEH CD-ROM accurately represented the catchment boundaries and catchment descriptors. ReFH conservatively estimates flow in permeable catchments.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	ReFH is not normally the preferred option for the permeable catchments at Capper's Lane viaduct (SWC-CFA22-001) and Mare Brook south culvert (SWC-CFA22-004). This method was applied to determine the scaling factors for the 1 in 1000 (0.1%) annual probability flow estimation as described in Section 0 of this report.
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH 3 12.5 or the factorial standard error from Science Report SC050050 (2008).	There is some uncertainty with the results based on the assumptions listed above, however it is considered that the results are conservative and hence would be overestimating, rather than underestimating flows.

[10] The 1 in 100 (1%) annual probability flow with an allowance for climate change is the 1 in 100 (1%) annual probability flow factored by 1.2.
[11] The ReFH flow estimates for these crossings are used to derive scaling factors for the 1 in 1000 (0.1%) annual probability flow in Section 3.3 of this report.

Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	The results have been completed for the purposes of the assessment of flood risk as the proposed crossings. The results should not be used for other studies with the exception for comparative purposes.
Give any other comments on the study, for example suggestions for additional work.	When the assessment moves to the detailed design phase it may be useful that the catchment boundaries are checked against LiDAR, OS mapping and other such sources. If possible the FEH Statistical method should be carried out for Mare Brook North culvert for comparative purposes and to provide a greater level of confidence with the results.

Checks

Are the results consistent, for example at confluences?	N/A
What do the results imply regarding the return periods of floods during the period of record?	N/A
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	Not determined.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	1.94
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	None.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	None.
Are the results compatible with the longer-term flood history?	None.
Describe any other checks on the results	None.

Final results

Site code	**Flood peak (m^3/s) for the following flood events**			
	1 in 20 (5%)	**1 in 100 (1%)**	**1 in 100 (1%) climate change**	**1 in 1000 (0.1%)**
SWC-CFA22-001[12]	0.43	1.00	1.20	3.28
SWC-CFA22-004[12]	0.55	0.84	1.01	1.73
SWC-CFA22-006	0.25	0.37	0.44	0.72

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)	Hydrographs not required for these crossings.

[12] The ReFH flow estimates for these crossings are used to derive scaling factors for the 1 in 1000 (0.1%) annual probability flow in Section 3.3.

3.3 Permeable catchment assessment – Capper's Lane viaduct and Mare Brook South culvert

Method statement

Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: Purpose of study Approx. no. of flood estimates required Peak flows or hydrographs? Range of return periods and locations Approx. time available	This assessment has been completed for the purposes of the Proposed Scheme. The initial assessment phase of river flood risk included an estimation of flow within watercourses to be crossed by the route. The initial assessment produced quick flow estimates through the use of the ReFH model. However, as part of the assessment it was determined that the two catchments that drain to the Capper's Lane viaduct (SWC-CFA22-001) and the Mare Brook south culvert (SWC-CFA22-004) were highly permeable in nature and hence the flood estimation guidelines[4] state that ReFH is not appropriate for these catchments. This calculation record outlines the estimation of flow for these two highly permeable catchments using the recommended approach. The flows are required to provide an indication of size requirements for the route crossings to prevent increases in flood risk as a result of the scheme. The flow will also be used to determine the 1 in 1000 (0.1%) annual probability flood level to ensure that the track is not at an unacceptable level of risk. At this stage it is necessary to follow a conservative approach, because it is vital that the culverts/bridges are not under-designed. It is acceptable at this stage that structures are over-designed and reduced (if necessary) during the detailed design phase. Flows are required for the 1 in 20 (5%) annual probability, 1 in 100 (1%) annual probability, 1 in 100 (1%) annual probability with an allowance for climate change and 1 in 1000 (0.1%) annual probability events. These flows are required at two locations. At this stage only peak flows (no hydrographs) are required. Approximately two days are available for the assessment.

Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The two catchments are shown on location plans included in Section 3.5 of this calculation record. These catchments are defined by FEH catchment descriptors as being highly permeable in nature. The catchments are named in accordance with the associated watercourse identifier and are located at Capper's Lane viaduct (SWC-CFA22-001) and the Mare Brook south culvert (SWC-CFA22-004). These two catchments which are located on the outskirts of Lichfield, are defined as moderately urbanised. Capper's Lane viaduct (SWC-CFA22-001) is primarily underlain with sandstones. Mare Brook south culvert (SWC-CFA22-004) is primarily underlain by sandstones in the upstream reaches and mudstones in the downstream reaches of the catchment.

Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 3.1.2, December 2011

Gauging stations (flow or level)

3.3.1 Gauging stations at the sites of flood estimates or nearby at potential donor sites.

3.3.2 Local donor sites have been sought however in most cases the catchment area of the subject catchment was found to be significantly smaller than that of any potential local donor.

Watercourse	Station name	Gauging authority number	National River Flow Archive number (used in FEH)	Grid reference	Catchment area (km²)	Type (rated/ ultrasonic/ level	Start and end of flow record
N/A							

Data available at each flow gauging station

Station name	Start and end of data in HiFlows UK	Update for this study?	Suitable for QMED	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers
N/A						
Give link/reference to any further data quality checks carried out						

Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
N/A			
Give link/reference to any rating reviews carried out			

Other data available and how it has been obtained

Type of data	Data relevant to this study	Data available?	Source of data and licence reference if from Environment Agency	Date obtained	Details
Check flow gaugings (if planned to review ratings)	No				
Historic flood data – give link to historic review if carried out.	No				
Flow data for events	No				
Rainfall data for events	No				
Potential evaporation data	No				
Results from previous studies	No				Quick estimates taken from the initial assessment phase for the proposed scheme. ReFH was utilised and was not considered ideal for permeable catchments (Section 3.2 of this report).

Type of data	Data relevant to this study	Data available?	Source of data and licence reference if from Environment Agency	Date obtained	Details
Other data or information (e.g. groundwater, tides)	No				

Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	FEH is appropriate for these two catchments. The catchments areas are 1.77 and 14.83 km^2 and hence are within the appropriate range for the application of FEH methods. These catchments are considered to be moderately urbanised and have $URBEXT_{2000}$ values of 0.067 and 0.119. The catchments are not considered complex.
Outline the conceptual model, addressing questions such as: **Where are the main sites of interest?** **What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…)** **Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir?** **Is there a need to consider temporary debris dams that could collapse?**	There are two sites of interest, these are located at proposed watercourse crossings which are required as part of the route. The crossings are located on different watercourses and hence have separate catchments. As a result of the scheme, flooding at the sites of interest is likely to be caused by peak flow rather than flood volumes. There are no reservoirs or temporary dam collapses that need to be considered at the sites of interest.
Any unusual catchment features to take into account? **e.g.** **highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20%** **highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments** **pumped watercourse – consider lowland catchment version of rainfall-runoff method** **major reservoir influence (FARL<0.90) – consider flood routing** **extensive floodplain storage – consider choice of method carefully**	The catchments are considered highly permeable, all with BFIHOST>0.65. As a result ReFH is not considered an appropriate method. The catchments are moderately urbanised with $URBEXT_{2000}$<0.125. The catchments are not located on pumped watercourses. There is no major reservoir influence at any of the two sites of interest, the catchments have FARL values of 0.908 and 1. It is not considered that the catchments have extensive floodplain storage.
Initial choice of method(s) and reasons **Will the catchment be split into subcatchments? If so, how?**	The FEH Statistical method has been applied to the two catchments. As part of this assessment the permeability adjustment method has also been carried out due to the permeable nature of these two catchments. A scaling method has been carried out to determine the 1 in 1000 (0.1%) annual probability flow, as discussed the section 'Estimation of 1 in 1000 (0.1%) annual probability flow'.

Software to be used (with version numbers)	FEH CD-ROM v3.0[13] WINFAP-FEH v3[14]

Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	Catchment area on FEH CD-ROM (km^2)	Revised catchment area if altered
SWC-CFA22-001	Ordinary Watercourse (tributary of Fisherwick Brook)	Capper's Lane viaduct	414750	309000	14.83	N/A
SWC-CFA22-004	Ordinary Watercourse (tributary of Mare Brook)	Mare Brook south culvert	414350	311250	1.77	N/A
Reasons for choosing above locations		Locations the route is proposed to cross the respective watercourses.				

Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT 2000	FPEXT
SWC-CFA22-001	0.908	0.31	0.862	3.96	31.3	670	16.55	0.0671	0.06
SWC-CFA22-004	1.000	0.31	0.688	1.26	22.9	664	25.73	0.1194	0.09

Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	The catchment boundaries were checked against OS mapping and appeared to be reasonable. It has been deemed appropriate to retain the FEH CD-ROM catchments for this assessment. This approach is consistent with flow estimations for all other route crossings as part of the overall assessment for the Proposed Scheme.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	The catchments were checked against geology mapping, and no changes were considered necessary.
Source of URBEXT	$URBEXT_{2000}$
Method for updating of URBEXT	$URBEXT_{2000}$ – A new FEH catchment descriptor. R&D Technical Report FD1919/TR. Environment Agency 2006.

[13] FEH CD-ROM v3.0 © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.
[14] WINFAP-FEH v3 © Wallingford HydroSolutions Limited and NERC (CEH) 2009.

Statistical method

Search for donor sites for QMED (if applicable)

Comment on potential donor sites **Mention:** **Number of potential donor sites available** **Distances from subject site** **Similarity in terms of catchment area, BFIHOST, FARL and other catchment descriptors** **Quality of flood peak data** **Include a map if necessary.** **Note that donor catchments should usually be rural.**	Donor sites were sought through three approaches. Firstly the identification of donors in close proximity to the subject sites using the FEH CD-ROM and the Hydrometric Register (CEH, 2008)[15]. This approach identified seven potential donors, although on inspection of the HiFlows data set, three were classed as unsuitable for pooling or QMED. Secondly four donors for each catchment were identified as the top four in a pooling group using the 'OK for pooling' HiFlows data set. Thirdly, a further four for each catchment were identified as the top four in a pooling group using the 'OK for QMED' HiFlows data set. These approaches identified a total of 12 possible donors for each catchment. It was not possible to identify any donors within 10km of the subject sites (between centroids). For Capper's Lane viaduct (SWC-CFA22-001), there are four donors within 50km and additional two donors within 100km. For Mare Brook south culvert (SWC-CFA22-004), there are four donors within 50km and additional three donors within 100km. The identified potential donors vary in similarity to the subject sites. Where possible the donor most similar to the subject site has been selected. Further detail is included in the next section ('Donor sites chosen and QMED adjustment factors'). The majority of the potential donors have fairly long records of gauged data, in excess of 30 years.

Donor sites chosen and QMED adjustment factors

Potential Donors for Capper's Lane viaduct (SWC-CFA22-001)

National River Flow Archive no.	Reasons for choosing or rejecting	Method (annual maxima or peaks over threshold)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)[16]
28095	Rejected – The catchment is too urban and too large in size in comparison to the subject catchment.	annual maxima	Not required	157.5	102.98	1.1563
28026	Chosen – The catchment is one of the closest in distance to the subject site (the others closer are not suitable). The data record covers 42 years and the adjustment factor is >1 and hence follows a conservative approach. The catchment geology is the same as the subject site.	annual maxima	Not required	52.1	36.94	1.1004
28053	Rejected – Even though the catchment descriptors are as similar to the subject site as 28026, the adjustment factor is <1 and hence would not follow a conservative approach.	annual maxima	Not required	27.7	28.81	0.9893

[15] Centre for Ecology and Hydrology, (2008), *UK Hydrometric Register*.
[16] Adjustment factor has been updated and include an allowance for distance from the subject site. The updated adjustment calculation is provided within the flood estimation guidelines (Environment Agency, 2012).

National River Flow Archive no.	Reasons for choosing or rejecting	Method (annual maxima or peaks over threshold)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)[16]
28002	Rejected – The FARL is too low.	annual maxima	Not required	17.5	18.56	0.9849
26802	Rejected – The catchment is too far from the subject site and the catchment descriptors are less similar in comparison to 28026. In addition the record length is short.	annual maxima	Would be required – 10 years of data.	0.1	0.43	0.9835
25019	Rejected – The SAAR is too high and the catchment is too far from the subject site.	annual maxima	Not required	6.1	3.74	1.0035
32029	Rejected – The catchment descriptors are less similar to the subject site in comparison to 28026 and the record length is short.	annual maxima	Would be required – 5 years of data.	2.5	1.42	1.0694
44006	Rejected – The SAAR is too high and the catchment is too far from the subject site.	annual maxima	Not required	0.9	0.85	1.0000
41016	Rejected – The catchment is too far from the subject site and the catchment descriptors are less similar in comparison to 28026.	annual maxima	Not required	13.7	5.12	1.0038
39036	Rejected – This donor is very similar in relation to suitability as 28026 (the chosen donor) however the adjustment factor is <1 and hence would not follow a conservative approach. As a result 28026 is preferred for this study.	annual maxima	Not required	0.5	0.69	0.9957
52015	Rejected – SAAR is too high and catchment is too far from the subject site.	annual maxima	Not required	3.4	3.04	1.0024
30014	Rejected – Catchment is not permeable enough and the SAAR is too low.	annual maxima	Not required	2.7	1.87	1.0235

Which version of the urban adjustment was used for QMED at donor sites, and why? **Note: The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8).**	Urban adjustment was carried out on the QMED using the recommended approach[17].

[17] Urban adjustment was required in line with the Environment Agency guidelines, page 45, because the subject site has an URBEXT2000>0.03. These guidelines also stated that the use of an urban adjustment factor based on SPRHOST (as in Winfap-FEH V3) is known to underestimate QMED in permeable catchments, particularly those with BFIHOST >0.8, such as this subject site. As a result the equation for estimating urban adjustment, using BFIHOST, has been used for this site.

Potential Donors for Mare Brook South culvert (SWC-CFA22-004)

NRFA no.	Reasons for choosing or rejecting	Method (annual maxima or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)[16]
28095	Rejected – The catchment is too urban and too large in size in comparison to the subject catchment.	annual maxima	Not required	157.46	102.98	1.1440
28026	Rejected – The catchment is significantly greater in size than the subject site and the catchment descriptors are less similar in comparison to 31026.	annual maxima	Not required	52.05	36.94	1.0973
28053	Rejected – Even though the catchment descriptors are as similar to the subject site as 31026, the adjustment factor is <1 and hence would not follow a conservative approach.	annual maxima	Not required	27.74	28.81	0.9892
28002	Rejected – The FARL is too low.	annual maxima	Not required	17.52	18.56	0.9838
76011	Rejected – SAAR is too high, the catchment is not permeable enough and the catchment is too far from the subject site.	annual maxima	Not required	1.82	2.02	0.9998
45817	Rejected – SAAR is too high and the catchment is too far from the subject site.	annual maxima	Not required	1.34	0.92	1.0024
32029	Rejected – The catchment descriptors are less similar to the subject site in comparison to 31026 and the record length is short.	annual maxima	Would be required – 5 years of data.	2.54	1.42	1.0657
44009	Rejected – The SAAR is too high, catchment is too permeable and the catchment is too far from the subject site.	annual maxima	Not required	1.69	0.90	1.0029
31026	Chosen – The catchment descriptors are most similar to the subject site in comparison to the other potential donors. In addition the adjustment factor is >1 and hence follows the conservative approach.	annual maxima	Not required	1.08	0.31	1.1436
31023	Rejected – The catchment is not permeable enough.	annual maxima	Not required	1.91	1.13	1.0466
205999	Rejected – The SAAR is too high, the FARL is slightly too low, the catchment is too far from the subject site. In addition the adjustment factor would significantly reduce the QMED and the record period is short.	annual maxima	Would be required – 11 years of data.	0.12	3.13	0.8500

NRFA no.	Reasons for choosing or rejecting	Method (annual maxima or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)[16]
27038	Rejected – The catchment is too far and the catchment descriptors are not as similar to the subject site in comparison to 31026.	annual maxima	Not required	1.33	0.55	1.0096
Which version of the urban adjustment was used for QMED at donor sites, and why? **Note: The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8).**				Urban adjustment was carried out on the QMED using the recommended approach[17].		

Overview of estimation of QMED at each subject site

Site code	Method	Initial estimate of QMED (m^3/s)	Data transfer				Final estimate of QMED (m^3/s)
			National River Flow Archive numbers for donor sites used (see section 'Donor sites chosen and QMED adjustment factors')	Distance between centroids dij (km)	asg	Moderated QMED adjustment factor, (A/B)a	
SWC-CFA22-001	DT	0.37	28026	24.97	0.279	1.1004	0.61
SWC-CFA22-004	DT	0.19	31026	73.23	0.106	1.1436	0.27
Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?					N/A		
Which version of the urban adjustment was used for QMED, and why?					In line with guidance, PRUAF using SPRHOST[18] for Mare Brook south culvert (SWC-CFA22-004) and PRUAF using BFIHOST for Capper's Lane viaduct (SWC-CFA22-001).		

Notes
Methods: DT – Data transfer; CD – Catchment descriptors alone.
When QMED is estimated from POT data, it should also be adjusted for climatic variation. Details should be added.
When QMED is estimated from catchment descriptors, the revised 2008 equation from Science Report SC050050should be used. If the original FEH equation has been used, say so and give the reason why.
The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8). The adjustment method used in WINFAP-FEH v3.0.003 is likely to overestimate adjustment factors for such catchments. In this case the only reliable flood estimates are likely to be derived from local flow data.
The data transfer procedure is from Science Report SC050050. The QMED adjustment factor A/B for each donor site is given in Table 3.3. This is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is (A/B)a times the initial estimate from catchment descriptors.
If more than one donor has been used, use multiple rows for the site and give the weights used in the averaging. Record the weighted average adjustment factor in the penultimate column.

[18] PRUAF estimated using SPRHOST, Bayliss et al (2007) and PRUAF estimated using BFIHOST, Kjeldsen (2010) as outlined in the Environment Agency guidelines.

Derivation of pooling groups

3.3.3 The composition of the pooling groups is given in the Section 3.5. Several subject sites may use the same pooling group.

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons Note also any sites that were investigated but retained in the group.	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
SWC-CFA22-001	Capper's Lane viaduct	No	One station (32029) was removed because it has a record length of only five years. 22003 was also removed because it was highly discordant. Two stations were added to ensure there were enough years of data following the permeability adjustment (removal of non-flood years).	L-CV = 0.258 L-skew = 0.143
SWC-CFA22-004	Mare Brook South culvert	No	One station (32029) was removed because it has a record length of only five years. One station (27010) was added to ensure there were enough years of data following the permeability adjustment (removal of non-flood years).	L-CV = 0.227 L-skew = 0.233

Notes
Pooling groups were derived using in WINFAP-FEH v3. The permeability adjustment procedure was carried out on the pooling group to remove the non-flood years.
The weighted average L-moments, before urban adjustment, can be found at the bottom of the Pooling-group details window in WINFAP-FEH.

Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution (location, scale and shape) after adjustments	Growth factor for 100-year return period
SWC-CFA22-001	P	Capper's Lane viaduct	Generalised logistic as recommended in FEH	Permeable and urban adjustment.	Growth curve has a shallower gradient in comparison to the non adjusted curve.	Non-adjusted = 2.92 Adjusted = 1.67
SWC-CFA22-004	P	Mare Brook South culvert	Generalised logistic as recommended in FEH	Permeable and urban adjustment.	Growth curve has a shallower gradient in comparison to the non adjusted curve.	Non-adjusted = 2.80 Adjusted = 1.43

Notes
Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis
A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters.
Urban adjustments to growth curves should use the version 3 option in WINFAP-FEH: Kjeldsen (2010).

Flood estimates from the Statistical method

Site code	Flood peak (m^3/s) for the following flood events			
	1 in 20 (5%)	1 in 100 (1%)	1 in 100 (1%) climate change	1 in 1000 (0.1%)
Non-adjusted				
SWC-CFA22-001	1.25	0.98	1.17	1.06
SWC-CFA22-004	0.52	0.76	0.92	1.32
Permeability and urban adjustment				
SWC-CFA22-001	0.92	1.01	1.22	1.10
SWC-CFA22-004	0.37	0.39	0.47	0.41

Estimation of 1 in 1000 (0.1%) annual probability flow

Scaling for in 1000 (0.1%) annual probability flow

3.3.4 The FEH Statistical method is not normally the most appropriate for use in determining the 1 in 1000 (0.1%) annual probability flow. The FEH flood estimation guidelines[4] states that the ReFH method can be used to determine a ratio between the 1 in 100 (1%) and 1 in 1000 (0.1%) annual probability flow, which can then be used to factor the 1 in 100 (1%) annual probability flow estimated using the FEH Statistical method. However, it has already been noted that the ReFH method is not ideal for these two catchments due to the BFIHOST values being greater than 0.65.

3.3.5 This assessment is to be used in the early stages of the design process, with the focus being not to under-design the crossing structures. When the detailed design is being completed at a later stage, it is probable that the hydrology will have to be revisited. It is therefore considered appropriate to carry out a scaling approach using flows determined through the FEH Statistical and ReFH methods at this stage.

3.3.6 It is also worthy to note that the 1 in 1000 (0.1%) annual probability flow is not to be used to size the structure. Where culverts are necessary it is only required that the structure has sufficient capacity for the 1 in 100 (1%) annual probability with an allowance for climate change (and associated freeboards). The 1 in 1000 (0.1%) annual probability flow is to be utilised to determine flood level to ensure the track is sufficiently above this level.

ReFH flows

3.3.7 These flows have been taken from the ReFH assessment of flows (Section 3.2 of this report) for the Proposed Scheme.

Site code	Flood peak (m^3/s) for the following flood events				
	1 in 20 (5%)	1 in 100 (1%)	1 in 100 (1%) climate change	1 in 1000 (0.1%)	Scaling factor ratio of 1 in 1000 (0.1%) flow to the 1 in 100 (1%) flow
SWC-CFA22-001	0.43	1.00	1.20	3.28	3.28
SWC-CFA22-004	0.55	0.84	1.01	1.73	2.05

Final estimates of 1 in 1000 (0.1%) annual probability flows

Site code	Flood peak (m^3/s)				
	FEH Stat 1 in 1000 (0.1%) perm non-adjusted[19]	FEH Stat 1 in 1000 (0.1%) perm adjusted[20]	Scaling factor ratio of 1 in 1000 (0.1%) flow to the 1 in 100 (1%) flow	Updated FEH Stat 1 in 1000 (0.1%) perm non-adjusted[19]	Updated FEH Stat 1 in 1000 (0.1%) perm adjusted[20]
SWC-CFA22-001	1.06	1.10	3.28	3.20	3.32
SWC-CFA22-004	1.32	0.41	2.05	1.57	0.80

Discussion and summary of results

Comparison of results from different methods

3.3.8 This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

Site code	Ratio of peak flow to FEH Statistical peak					
	1 in 2 (50%) annual probability			1 in 100 (1%) annual probability		
	ReFH	Other method	Other method	ReFH	Other method	Other method
SWC-CFA22-001				0.99		
SWC-CFA22-004				2.15		

Final choice method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	The FEH Statistical method is the preferred choice due to the permeability nature of the catchments. The permeability adjustment procedure has been applied to the pooling group to remove non-flood years; however the result of the permeability adjustment on the growth curve is a reduction in flood flows in comparison to a non-adjusted growth curve. Urban adjustment has also been applied to both the QMED and the growth curve. The guidance states that ReFH is not appropriate for these catchments and hence the flows estimated using FEH Statistical with urban and permeability adjustment have been used (as recommended within the guidelines). In line with the FEH flood estimation guidelines[4] the scaling factor, taken from the ReFH flows, has been used to determine the flow for the 1 in 1000 (0.1%) annual probability event.

[19] Includes urban adjustment on QMED but not urban adjustment on growth curve.
[20] Includes urban adjustment on QMED and growth curve.

Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	It has been assumed that the catchments as delimited in the FEH CD-ROM are correct. The catchments appear reasonable through brief catchment boundary checking, but there is potentially some uncertainty with the urban areas contributing to flow within the catchments. This is not considered a concern at this stage, but it may be something worth assessing for the detailed design phase. Assumptions have been made in the estimation of the 1 in 1000 (0.1%) annual probability flow. It is recognised that the method undertaken does not wholly comply with the guidelines; however given the use of the 1 in 1000 (0.1%) annual probability flow within the study and that the most conservative value has been taken forward, this approach is considered acceptable. The calculation QMED has been altered based on donor catchments; it is assumed that the donor catchment are suitable.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	The scaling factor for the 1 in 1000 (0.1%) annual probability flow was determined from the ReFH methods. It is not normally recommended that the ReFH method is used for flow estimation in permeable catchments such as these. It should also be noted that urban, highly permeable catchments are outside the range of the vast majority of catchments from which FEH methods have been developed. The guidance[4] states that there is very little data on the effects of urbanisation on highly permeable catchments, hence there is inherent uncertainty within the flood flows estimated as there is no measured flow data.
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH 3 12.5 or the factorial standard error from Science Report SC050050 (2008).	There is potential that the flows provided within this calculation record overestimated flows, however this is considered acceptable for the purposes of this study. Even though there is potential that the flows have been over estimated, there is also a chance that flows may have been under estimated. However given a conservative approach that has been taken in some aspects of this assessment and for the overall modelling it is considered that the overall results are unlikely to be an underestimation.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	The flow estimates up to and including the 1 in 100 (1%) annual probability flow values would be considered acceptable for information in future studies. However new estimates would be necessary if flows were required at locations either upstream or downstream from the point of interest. It is not recommended that the results for the 1 in 1000 (0.1%) annual probability event are utilised in future studies.
Give any other comments on the study, for example suggestions for additional work.	Although not anticipated to be necessary, a detailed assessment of the catchment boundaries could be carried out, particularly for the urban contributions to the catchments. The FEH Rainfall-runoff method could also be applied to provide a better estimate of the 1 in 1000 (0.1%) annual probability flow if deemed necessary at a later stage.

Checks

Are the results consistent, for example at confluences?	N/A
What do the results imply regarding the return periods of floods during the period of record?	No flood events to compare to.
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	Growth factor not taking into account permeable adjustment is 2.80 and 2.92. Taking into account permeable adjustment the growth factor is 1.43 and 1.67.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	A scaling factor between 1 in 100 (1%) and 1 in 1000 (0.1%) annual probability flows was applied. The factors were 2.05 and 3.27 in this assessment.
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	N/A
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	No other studies used for comparison. ReFH flows estimated from an earlier study were utilised for this assessment, see section 4.
Are the results compatible with the longer-term flood history?	No history to compare to.
Describe any other checks on the results	No other checks.

Final results

Site code	**Flood peak (m^3/s) for the following flood events**			
	1 in 20 (5%)	**1 in 1000 (1%)**	**1 in 100 (1%) climate change**	**1 in 1000 (0.1%)**
SWC-CFA22-001	0.92	1.01	1.22	3.32
SWC-CFA22-004	0.37	0.39	0.47	0.80
If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)			Hydrographs not required at this stage.	

3.4 Pyford Brook viaduct, Bourne Brook viaduct, Handsacre East culvert and Handsacre West culvert extension

Method statement

Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: Purpose of study Approx. no. of flood estimates required Peak flows or hydrographs? Range of return periods and locations Approx. time available	This proforma outlines the hydrological calculations carried out for four crossings Pyford Brook viaduct (SWC-CFA22-010), Bourne Brook viaduct (SWC-CFA22-012), Handsacre East culvert (SWC-CFA22-017) and Handsacre West culvert extension SWC-CFA22-018. As part of the Proposed Scheme, structures may need to be incorporated into the design where a number of watercourses pass beneath the proposed route of the Proposed Scheme. The capacity of these structures needs to be determined to ensure there is no increase to flood risk. It is vital at this stage that the proposed structures are not under designed and hence conservative flows are necessary in line with current requirements of the Proposed Scheme. At a later stage, if a more in-depth assessment determines lower flows, and hence smaller structures would have sufficient capacity, this is acceptable. Flows estimated for the route watercourse crossings along the 75km northern section of the Proposed Scheme (from north of Lichfield to Banbury) have been used to inform this assessment. Flows are required where the route will cross all watercourses. This assessment outlines the derivation of flows and hydrographs at four locations for the 1 in 20 (5%) annual probability, 1 in 100 (1%) annual probability, 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability.

Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The four crossings have separate catchments which have sizes from <1km^2 to 28.47km^2. The level of urbanisation in the catchments ranges from entirely rural to heavily urbanised.

Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 3.1.2, December 2011

Gauging stations (flow or level)

3.4.1 Gauging stations at the sites of flood estimates or nearby at potential donor sites.

3.4.2 Local donor sites have been sought however in most cases the catchment area of the subject catchment was found to be significantly smaller than that of any potential local donor.

Watercourse	Station name	Gauging authority number	National River Flow Archive number (used in FEH)	Grid reference	Catchment area (km²)	Type (rated/ ultrasonic/ level	Start and end of flow record
N/A							

Data available at each flow gauging station

Station name	**Start and end of data in HiFlows UK**	**Update for this study?**	**Suitable for QMED**	**Suitable for pooling?**	**Data quality check needed?**	**Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers**
N/A						
Give link/reference to any further data quality checks carried out						

Rating equations

Station name	**Type of rating e.g. theoretical, empirical; degree of extrapolation**	**Rating review needed**	**Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.**
N/A			
Give link/reference to any rating reviews carried out			

Other data available and how it has been obtained

Type of data	**Data relevant to this study**	**Data available?**	**Source of data and licence reference if from Environment Agency**	**Date obtained**	**Details**
Check flow gaugings (if planned to review ratings)	No				
Historic flood data – give link to historic review if carried out.	No				
Flow data for events	No				
Rainfall data for events	No				
Potential evaporation data	No				
Results from previous studies	No				
Other data or information (e.g. groundwater, tides)	No				

Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	Yes. There are two crossings Handsacre East culvert (SWC-CFA22-017) and Handsacre West culvert extension (SWC-CFA22-018) which have small catchments <0.5km^2. Current guidance recommends that for catchments smaller than 0.5km^2, runoff estimates should be derived from FEH methods applied to the nearest suitable catchment above 0.5km^2 for which descriptors can be derived from the FEH CD-ROM and scaled down. The catchment of one crossing, Pyford Brook viaduct (SWC-CFA22-010), may be defined as very heavily urbanised. For this catchment the FEH Statistical method with an urban adjustment will be considered as well as the ReFH method. The bullet points below summarise the general approach to flow estimation for minor watercourses and the larger watercourses and main rivers. Minor watercourses at Handsacre West culvert extension (SWC-CFA22-018) and Handsacre East culvert (SWC-CFA22-017): - define catchment area either on the FEH CD-ROM or using the DTM if catchment area is <0.5km^2; - check catchment descriptors and adjust where necessary; - calculate critical duration for the catchment of each crossing using the equation D (hrs) = Tp*(1+SAAR/1000); and - calculate flows using the ReFH method from catchment descriptors. Main rivers and larger watercourses at Pyford Brook viaduct (SWC-CFA22-010) and Bourne Brook viaduct (SWC-CFA22-012): - extract catchment descriptors from the FEH CD-ROM and check; - search for a local donor station (using the FEH CD-ROM and in pooling group); - derive flow estimates using both ReFH and FEH Statistical methods; - calculate critical duration for the catchment of each crossing using the equation, D (hrs) = T_p*(1+SAAR/1000); - review existing hydrology studies for the catchments of major crossings where available; and - compare flow estimates and make recommendations for flows to be used in modelling.
Outline the conceptual model, addressing questions such as: **Where are the main sites of interest?** **What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides...)** **Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir?** **Is there a need to consider temporary debris dams that could collapse?**	The main sites of interest are at the crossing locations and hence are the points at which flow has been derived. Each point at which flow has been derived has been named in accordance with the associated watercourse identifier. However, it should be noted that the catchments at crossings Handsacre East culvert (SWC-CFA22-017) and Handsacre West culvert extension (SWC-CFA22-018) are two of four catchments which drain to a single watercourse. Therefore, the site code for this watercourse will be referred as a unique identifier in this proforma section. It was considered that peak flows are likely to be the main cause of flooding, following development, due to the potentially constricting culvert or bridge. There is a reservoir present upstream of Bourne Brook. The operation of the reservoir is unknown at this stage. As part of this assessment it is not currently deemed necessary to consider the risk of a temporary dam collapse; however this may be considered in future.

Any unusual catchment features to take into account? **e.g.** **highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20%** **highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments** **pumped watercourse – consider lowland catchment version of rainfall-runoff method** **major reservoir influence (FARL<0.90) – consider flood routing** **extensive floodplain storage – consider choice of method carefully**	The catchment at Pyford Brook viaduct (SWC-CFA22-010) has BFIHOST greater than 0.65, however SPRHOST for the catchment is greater than 20%. Given the SPRHOST is greater than 20% the ReFH method is considered suitable. Pyford Brook viaduct (SWC-CFA22-010) is a larger crossing of the Curborough Brook and also has an $URBEXT_{1990}$ value <0.125. As this is a major crossing both the ReFH and the FEH Statistical method will be undertaken and compared. All other catchments are within a suitable range of urbanisation for the ReFH method. All catchments have a FARL >0.9.
Initial choice of method(s) and reasons **Will the catchment be split into sub-catchments? If so, how?**	For the purposes of this assessment two levels of assessment have been undertaken for crossings of minor watercourses and for crossings of major watercourses. The choice of method for each assessment is summarized below. Crossings of minor watercourses [Handsacre East culvert (SWC-CFA22-017) and Handsacre West culvert extension (SWC-CFA22-018)]: - calculate flows using the ReFH method from catchment descriptors. Crossings of main rivers/ larger watercourses [Pyford Brook viaduct (SWC-CFA22-010) and Bourne Brook viaduct (SWC-CFA22-012)]: - derive flow estimates using both ReFH and FEH Statistical pooling group methods; and - review existing hydrology studies for the catchments of major crossings where available. It should be noted that there are four small catchments draining into the same watercourse including those at crossings Handsacre East culvert (SWC-CFA22-017) and Handsacre West culvert extension (SWC-CFA22-018). These are all small catchments <1km^2.Flow will be estimated to a point downstream of crossings (national grid reference 409700, 315350) and distributed based on the catchment area for each crossing.
Software to be used (with version numbers)	FEH CD-ROM v3.0[21] WINFAP-FEH v3.0[22] ReFH calculations – ReFH spreadsheet / ISIS

[21] FEH CD-ROM v3.0 © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.
[22] WINFAP-FEH v3 © Wallingford HydroSolutions Limited and NERC (CEH) 2009.

Summary of subject sites

Site code (taken from watercourse identifier/unique identifier)	Watercourse	Site	Easting	Northing	Catchment area on FEH CD-ROM (km^2)	Revised catchment area if altered
191-192	Ordinary watercourse (no unique watercourse ID)	A point downstream of the crossings (national grid reference 409700, 315350).	There are four small catchments draining into the same watercourse including those at crossings Handsacre East culvert (SWC-CFA22-017) and Handsacre West culvert extension (SWC-CFA22-018). These are all small catchments <1km^2.Flow will be estimated to a point downstream of crossings (national grid reference 409700, 315350) and distributed based on the catchment area for each crossing. The catchment area of the flow estimation location is incorrect on the FEH CD-ROM, the catchment boundary has been checked using the DTM and increased by 0.60km^2. The DTM has been used to define the small catchment areas for the crossings.			Total area to a point downstream of the crossings used in flow estimation is 1.69km^2. Individual catchment areas used in area weighting: Handsacre East culvert (SWC-CFA22-017)= 0.18 km^2 Handsacre West culvert extension (SWC-CFA22-018)= 0.41 km^2
SWC-CFA22-012	Bourne Brook (ordinary watercourse)	Bourne Brook viaduct	410850	314150	28.47	Not altered
SWC-CFA22-010	Main river (Curborough Brook)	Pyford Brook viaducts	413050	313400	17.19	Not altered
Reasons for choosing above locations		Locations the Proposed Scheme crosses the respective watercourses.				

Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT 2000	FPEXT
191-192	1.000	0.31	0.624	1.33	28.5	692	29.96	0.0110	0.0106
SWC-CFA22-012	0.962	0.31	0.635	6.66	47.5	722	30.22	0.0565	0.0557
SWC-CFA22-010	0.946	0.31	0.669	4.82	27.9	682	26.75	0.1550	0.1906

Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	The boundary of each catchment has been checked against contours from OS 50K mapping and DTM where available. Adjustment to the catchment boundaries and area was made where necessary. The boundary of catchments not represented on the FEH CD-ROM was determined using the DTM. Changes to the catchment boundary and resulting area are provided in table of 'Summary of subject sites'.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	This proforma outlines the hydrological assessment for the initial stage of assessment. Broad scale checks of catchment descriptors have been carried out. The catchment descriptors for catchments not represented on the FEH CD-ROM were extracted for downstream or any adjacent catchment. The FEH CD-ROM catchment area was adjusted and the DPLBAR was recalculated based on the new area (catchment area^0.548). The average slope has been calculated using the Weighted Height-Distance Method. Other catchment descriptors were sensibility checked for suitability. For all catchments, where the catchment area has changed the new catchment area has been used to calculate the DPLBAR (catchment area^0.548). The underlying geology and soils have been reviewed on a broad scale for the larger area of interest and the catchment values for BFIHOST and SPRHOST values appear reasonable, no changes were considered necessary at this stage.
Source of URBEXT	URBEXT1990 (ReFH method) / URBEXT2000 (FEH Statistical Method)
Method for updating of URBEXT	CPRE formula from FEH Volume 4 on URBEXT1990 / CPRE formula from 2006 CEH report on URBEXT2000.

Statistical method

3.4.3 Peak flows from the FEH Statistical method have been calculated at the Bourne Brook viaduct (SWC-CFA22-012) and Pyford Brook viaduct (SWC-CFA22-010). These flow estimates were used for comparison with flow estimates derived from the ReFH method.

Search for donor sites for QMED (if applicable)

Comment on potential donor sites **Mention:** **Number of potential donor sites available** **Distances from subject site** **Similarity in terms of catchment area, BFIHOST, FARL and other catchment descriptors** **Quality of flood peak data** **Include a map if necessary.** **Note that donor catchments should usually be rural.**	Potential donor sites were sought for the catchments of the major crossings using the FEH CD-ROM, HiFlows-UK database and from within the pooling groups. Stations within a reasonable distance of the catchments of the crossings were either significantly larger, heavily urbanised or had very different catchment descriptors and were considered unsuitable donor stations. The asg factor applied to more distant potential donor stations negated the adjustment of QMED.

Donor sites chosen and QMED adjustment factors

National River Flow Archive no.	Reasons for choosing or rejecting	Method (annual maxima or peaks over threshold)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)
No suitable donor stations have been identified. QMED has been calculated from catchment descriptors. Please refer to comments in the section 'Search for donor sites for QMED (if applicable)'.						

Which version of the urban adjustment was used for QMED at donor sites, and why? **Note: The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8).**	

Overview of estimation of QMED at each subject site

Site code	Method	Initial estimate of QMED (m^3/s)	Data transfer	Final estimate of QMED (m^3/s)
SWC-CFA22-012	CD	2.906	N/A	2.906
SWC-CFA22-010	CD	1.603	N/A	1.603

Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?	N/A – Estimates for different catchments
Which version of the urban adjustment was used for QMED, and why?	Bayliss (2007) – appropriate method at the time of the assessment.

Derivation of pooling groups

3.4.4 The composition of the pooling groups is given in the Annex. Several subject sites may use the same pooling group.

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons Note also any sites that were investigated but retained in the group.	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
Bourne Brook @ Cro6	SWC-CFA22-012	No	Details provided in Section 3.5.	
Curborough Brook @ Cro9	SWC-CFA22-010	No	Details provided in Section 3.5.	

Notes
Pooling groups were derived using the revised procedures from Science Report SC050050 (2008). The weighted average L-moments, before urban adjustment, can be found at the bottom of the Pooling-group details window in WINFAP-FEH.

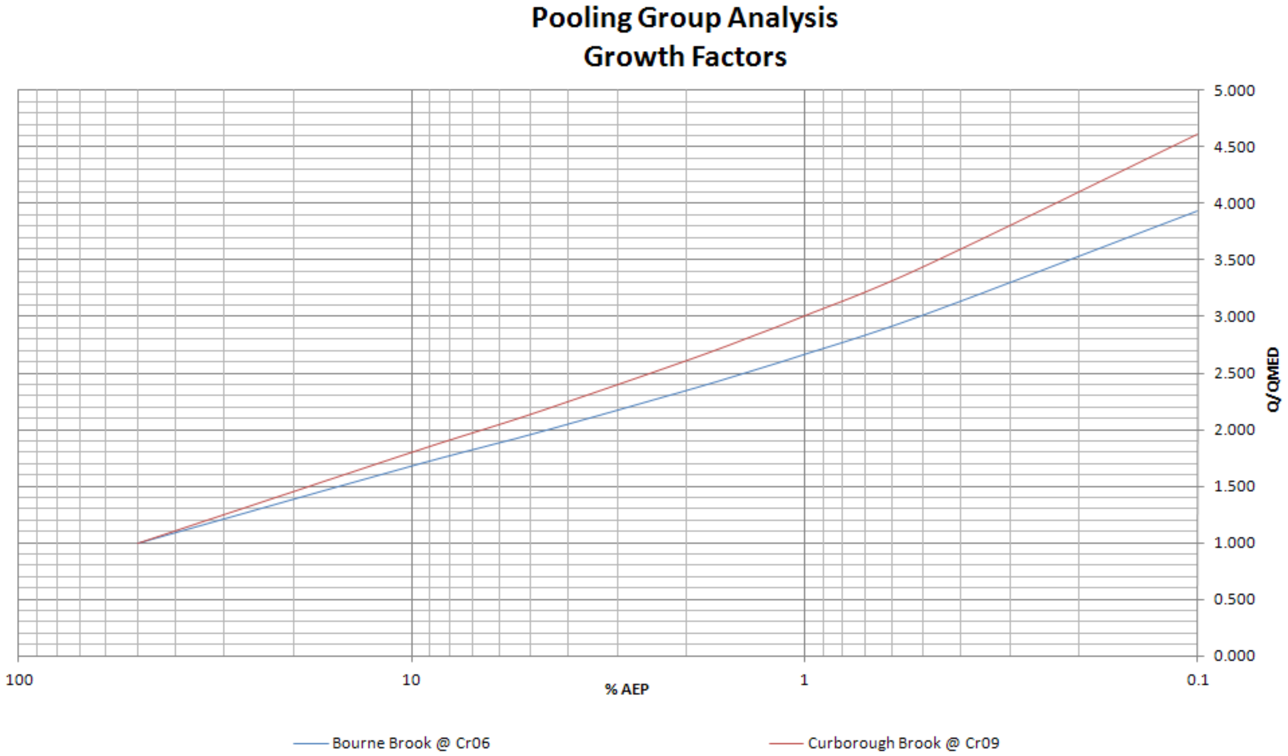
Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution (location, scale and shape) after adjustments	Growth factor for 1 in 100 (1%)
SWC-CFA22-012	P	Bourne Brook @ Cr06	Generalised logistic as recommended in FEH	Urban adjustment Kjeldsen (2010)	Location 1 Scale 0.26 Shape -0.13 Bound -1.02	2.672
SWC-CFA22-010	P	Curborough Brook @ Cr09	Generalised logistic as recommended in FEH	Urban adjustment Kjeldsen (2010)	Location 1 Scale 0.278 Shape -0.168 Bound -0.653	3.012

Notes
Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis
A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters.
Urban adjustments to growth curves should use the version 3 option in WINFAP-FEH: Kjeldsen (2010).

Flood estimates from the Statistical method

Site code	Flood peak (m^3/s) for the following flood events							
	1 in 2 (50%)	1 in 10 (10%)	1 in 20 (5%)	1 in 50 (2%)	1 in 100 (1%)	1 in 100 (1%) climate change	1 in 200 (0.5%)	1 in 1000 (0.1%)
SWC-CFA22-012	2.91	4.85	5.65	6.78	7.31	7.71	8.72	11.46
SWC-CFA22-010	1.60	2.79	3.30	4.06	4.42	4.70	5.42	7.43



Revitalised flood hydrograph (ReFH) method

Parameters for ReFH model

3.4.5 Note: If parameters are estimated from catchment descriptors, they are easily reproducible so it is not essential to enter them in the table.

Site code	Method OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	T_p (hours) Time to peak	C_{max} (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
191-192	CD	2.51	504.96	39.06	1.48
SWC-CFA22-012	CD	4.93	513.41	48.36	1.51
SWC-CFA22-010	CD	3.50	539.49	35.41	1.59
Brief description of any flood event analysis carried out (further details should be given below or in a project report)			Potential donor sites were sought for the catchments of major crossings using the FEH CD-ROM, HiFlows-UK database and from within the pooling groups. In general stations local to the catchments were either significantly larger, heavily urbanised or had very different catchment descriptors and were unsuitable donor stations.		

Design events for ReFH method

Site Code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
191-192	Rural	Winter	4.2	ReFH Design Standard
SWC-CFA22-012	Urban	Summer	8.5	ReFH Design Standard
SWC-CFA22-010	Urban	Summer	5.9	ReFH Design Standard
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?			Storm durations will not be altered during the next stage of the hydraulic modelling.	

Flood estimates from the ReFH method

Site Code	Flood peak (m^3/s) for the following flood events			
	1 in 20 (5%)	1 in 100 (1%)	1 in 100 (1%) climate change[23]	1 in 1000 (0.1%)
191-192	0.63	0.93	1.12	1.79
SWC-CFA22-012	7.33	10.61	12.73	19.82
SWC-CFA22-010	4.71	7.05	8.46	15.51

Discussion and summary of results

Comparison of results from different methods

3.4.6 This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

[23] The 1 in 100 (1%) annual probability flow with an allowance for climate change is the 1 in 100 (1%) annual probability flow factored by 1.2.

Site code	Ratio of peak flow to FEH Statistical peak			
	1 in 2 (50%) annual probability		1 in 100 (1%) annual probability	
	ReFH	FEH Statistical pooling group	ReFH	FEH Statistical pooling group
191-192	0.63		0.93	
SWC-CFA22-012	7.33	5.65	10.61	7.71
SWC-CFA22-010	4.71	3.30	7.05	4.70

Final choice method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	There are four small catchments draining into the same watercourse including those at crossings Handsacre West culvert extension and Handsacre East culvert. These are all small catchments <1km^2. Flows were estimated using the ReFH method from catchment descriptors extracted from the FEH CD-ROM to a point downstream of crossings (national grid reference 409700, 315350) and then distributed based on the catchment area for each crossing using the catchment areas detailed in "Summary of subject sites". A comparison of the peak flows from the FEH Statistical method have been provided for two major crossings of the Bourne Brook and the Curborough Brook (Bourne Brook viaduct and Pyford Brook viaduct). The catchment of the Curborough Brook crossing is heavily urbanised and the FEH Statistical method is arguably the most appropriate method. However for both crossings (Bourne Brook viaduct and Pyford Brook viaduct) the peak flow estimates from the ReFH method are larger. It is vital at this stage that the proposed structures are not under designed and hence conservative flows are necessary in line with current requirements of the Proposed Scheme. Therefore peak flows from the ReFH method have been used in modelling for all crossings.

Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	Crossings Handsacre West culvert extension and Handsacre East culvert drain to the same watercourse. Flows have been estimated to a point downstream of the crossings (national grid reference 409700, 315350) and distributed based on the catchment area for each crossing. The resulting peak flows at this point downstream, Handsacre West culvert extension and Handsacre East culvert are provided in the table of 'Final results' section.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	ReFH would not normally be the preferred option for crossing Pyford Brook viaduct due to the urban nature of the catchment. However this stage of the study requires conservative flow estimates for design purposes and therefore the ReFH method peak flow estimate has been used for this catchment.
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH 3 12.5 or the factorial standard error from Science Report SC050050 (2008).	There is some uncertainty with the results, however it is considered that the results are conservative and hence would be over estimating, rather than under estimating.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	Peak flow estimates have been produced for the purposes of this assessment and should not be used outside of this study except for comparative purposes.
Give any other comments on the study, for example suggestions for additional work.	When the assessment moves to the detailed design phase the FEH Statistical method should be carried out for all suitable catchments for comparative purposes and to provide a greater level of confidence with the results. If there is the opportunity to install temporary flow gauges at the un-gauged crossings, this may also improve confidence in design flows at the detailed design phase.

Checks

Are the results consistent, for example at confluences?	N/A Separate catchments assessed.
What do the results imply regarding the return periods of floods during the period of record?	N/A
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	Not determined for ReFH method.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	Range between 1.87 and 2.2.
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	Different catchments so not comparable.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	None.
Are the results compatible with the longer-term flood history?	Not investigated as part of the initial assessment.
Describe any other checks on the results	None.

Final results

Site code	Flood peak (m^3/s) for the following flood events			
	1 in 20 (5%)	1 in 100 (1%)	1 in 100 (1%) climate change	1 in 1000 (0.1%)
191-192	0.63	0.93	1.12	1.79
SWC-CFA22-018	0.15	0.23	0.27	0.44
SWC-CFA22-017	0.07	0.10	0.12	0.19
SWC-CFA22-012	7.33	10.61	12.73	19.82
SWC-CFA22-010	4.71	7.05	8.46	15.51

3.5 Supporting information

Default pooling groups

Capper's Lane viaduct (SWC-CFA22-001)

Name	nYears	L-CV	L-skew	Discordancy	Distance
26802 (Gypsey Race @ Kirby Grindalythe)	10	0.233	0.25	0.387	0.738
25019 (Leven @ Easby)	31	0.355	0.396	1.086	0.871
44006 (Sydling Water @ Sydling st Nicholas)	35	0.227	0.087	0.038	1.049
36010 (Bumpstead Brook @ Broad Green)	42	0.428	0.223	1.173	1.092
36009 (Brett @ Cockfield)	39	0.26	-0.113	1.493	1.125
27010 (Hodge Beck @ Bransdale Weir)	41	0.224	0.293	0.668	1.173
203046 (Rathmore Burn @ Rathmore Bridge)	27	0.126	0.125	0.81	1.184
44008 (Sth Winterbourne @ W'bourne Steepleton)	30	0.382	0.325	0.871	1.204
20002 (West Peffer Burn @ Luffness)	41	0.292	0.015	0.664	1.218
27051 (Crimple @ Burn Bridge)	37	0.22	0.133	1.238	1.257
44009 (Wey @ Broadwey)	32	0.34	0.241	0.246	1.305

Name	nYears	L-CV	L-skew	Discordancy	Distance
50009 (Lew @ Norley Bridge)	20	0.13	-0.243	2.472	1.399
41020 (Bevern Stream @ Clappers Bridge)	40	0.229	0.22	0.207	1.439
203049 (Clady @ Clady Bridge)	27	0.197	0.123	0.216	1.443
206004 (Bessbrook @ Carnbane)	25	0.23	0.37	1.314	1.491
73015 (Keer @ High Keer Weir)	19	0.076	-0.225	1.786	1.506
72014 (Conder @ Galgate)	42	0.192	0.058	1.755	1.509
44809 (Piddle @ Little Puddle)	16	0.456	0.266	1.574	1.525
TOTAL	554				
Weighted means		0.258	0.143		

Mare Brook South culvert (SWC-CFA22-004)

Name	nYears	L-CV	L-skew	Discordancy	Distance
76011 (Coal Burn @ Coalburn)	32	0.178	0.347	0.837	0.993
45817 (Rhb Trib to Haddeo @ Upton (trib))	16	0.292	0.304	0.396	1.433
44009 (Wey @ Broadwey)	32	0.34	0.241	1.395	2.349
27051 (Crimple @ Burn Bridge)	37	0.22	0.133	0.527	2.369
45816 (Haddeo @ Upton)	16	0.331	0.427	0.971	2.393
27073 (Brompton Beck @ Snainton Ings)	29	0.205	0.011	1.047	2.657
28033 (Dove @ Hollinsclough)	30	0.257	0.403	0.479	2.677
54091 (Severn @ Hafren Flume)	34	0.184	0.27	2.629	2.861
54092 (Severn @ Hore Flume)	34	0.116	-0.052	2.496	2.881
44006 (Sydling Water @ Sydling st Nicholas)	35	0.227	0.087	0.614	2.965
25019 (Leven @ Easby)	31	0.355	0.396	1.318	3.138
26802 (Gypsey Race @ Kirby Grindalythe)	10	0.233	0.25	0.084	3.156
25011 (Langdon Beck @ Langdon)	23	0.247	0.399	1.268	3.28
91802 (Allt Leachdach @ Intake)	34	0.153	0.257	1.096	3.317
25003 (Trout Beck @ Moor House)	36	0.173	0.328	0.769	3.35
206006 (Annalong @ Recorder 1895)	48	0.189	0.052	1.298	3.48
54022 (Severn @ Plynlimon Flume)	38	0.156	0.171	0.676	3.492
27010 (Hodge Beck @ Bransdale Weir)	41	0.224	0.293	0.1	3.522
TOTAL	556				
Weighted means		0.227	0.233		

Amendments to default pooling groups for Pyford Brook viaduct (SWC-CFA22-010) and Bourne Brook viaduct (SWC-CFA22-012)

Pyford Brook viaduct (Curborough Brook)

Subject catchment information	
Crossing	Curborough Brook @ Pyford Brook Viaduct (Cr09)
National grid reference	413050, 313400
Area	17.19km²
Permeability	Not permeable (BFIHOST < 0.75 and SPRHOST > 20%)
Urbanisation	Heavily urbanised (URBEXT2000 > 0.15)
Target return period	100
Required years of data	500

Pyford Brook viaduct default pooling group

Name	nYears	L-CV	L-Skew	Discordancy	Distance
54060 (Potford Brook @ Sandyford Bridge)	31	0.46	0.36	1.46	0.68
41016 (Cuckmere @ Cowbeech)	41	0.33	0.10	0.53	0.71
41028 (Chess Stream @ Chess Bridge)	44	0.22	0.18	1.02	0.71
36009 (Brett @ Cockfield)	38	0.26	-0.10	1.57	0.74
30014 (Pointon Lode @ Pointon)	36	0.41	0.33	1.37	0.78
52015 (Land Yeo @ Wraxall Bridge)	29	0.30	0.11	0.15	0.79
26802 (Gypsey Race @ Kirby Grindalythe)	8	0.20	0.19	2.59	0.79
20002 (West Peffer Burn @ Luffness)	41	0.29	0.02	1.16	0.82
39017 (Ray @ Grendon Underwood)	42	0.35	0.10	0.52	0.86
39036 (Law Brook @ Albury)	41	0.26	0.09	0.84	0.90
31025 (Gwash South Arm @ Manton)	30	0.28	0.08	0.27	0.91
7006 (Lossie @ Torwinny)	19	0.28	0.11	0.15	0.92
52016 (Currypool Stream @ Currypool Farm)	38	0.28	0.27	1.10	0.92
36010 (Bumpstead Brook @ Broad Green)	41	0.43	0.24	0.97	0.95
25019 (Leven @ Easby)	30	0.36	0.41	1.30	0.96
TOTAL	509				
Weighted means		0.32	0.16		

Pyford Brook viaduct pooling group review

Comment	Information	Decision	Station years
Discordant sites	None		
Period of record (<8 years?)	26802 (Gypsey Race @ Kirby Grindalythe) has 8 years of data (not flagged as 'short in WinFap)	As < 8 years recommended in FEH guidelines – not enough reason to remove.	509
Assessment of sites flagged on the HiFlows-UK database as 'No Pooling' and No Pooling / No QMED' and sites with permeable catchments or major catchment differences.	54060 (Potford Brook @ Sandyford Bridge) the top 11 annual maxima events are out-of-bank and the rating has not been developed beyond bank full – flows have been extrapolated.	Retain – not enough information to remove	509
	41016 (Cuckmere @ Cowbeech) No gaugings at highest flows, high flows often out of bank.	Retain – not enough information to remove	509
	41028 (Chess Stream @ Chess Bridge) No gaugings for verification of rating, possible bypassing and drowning.	Retain – not enough information to remove	509
	30014 (Pointon Lode @ Pointon) Theoretical rating for Crump weir with broad crested weir on either side. Correction to rating to remove 1m stage. Flow is non-modular and out of bank at the third highest annual maxima.	Retain – not enough information to remove	509
	26802 (Gypsey Race @ Kirby Grindalythe)	Remove – very permeable site (SPRHOST = 5.7) also has a short record.	501
	52015 (Land Yeo @ Wraxall Bridge) Doubt in rating at higher flows, unconfirmed by gaugings.	Retain – not enough information on data record to remove. SAAR and DPSBAR are high compared to the subject catchment however other CDs are good.	501
	39017 (Ray @ Grendon Underwood) At extreme flows above bank full, rating does not seem to measure flows accurately. Rating appears to be accurate whilst weir modular, but more gaugings are required and does not apply above bankfull.	Retain – not enough information to remove	501
	39036 (Law Brook @ Albury) Rating underestimates flows by around 25% at QMED value, though more gaugings are required to determine extent of problem. Flow is within bank full.	Retain – No reason to remove.	492
	31025 (Gwash South Arm @ Manton) Modular limit is approx 15 m3/s and highest flows may exceed this, with bypassing.	Retain – not enough information to remove	492
	7006 (Lossie @ Torwinny) Geographically distant (located in the north of Scotland), affected by ice. Not suitable for estimation of QMED or pooling; control is sensitive to floods.	Remove – Geographically distant, differences in catchment and poor data.	473

Comment	Information	Decision	Station years
	52016 (Currypool Stream @ Currypool Farm) High flows out of bank, no confirmation of high flow rating. The present rating is acceptable for levels to 0.4m but needs to be confirmed by gaugings between 0.4-0.8m.	Retain – not enough information to remove.	473
	25019 (Leven @ Easby) Catchment is significantly stepper than the subject catchment.	Remove	443

Pyford Brook viaduct added stations

Name	nYears	L-CV	L-Skew	Discordancy	Distance
43019 (Shreen Water @ Colesbrook)	35	0.20	0.00	0.55	1.03
45013 (Tale @ Fairmile)	24	0.21	0.20	1.20	1.17

Pyford Brook viaduct reviewed pooling group

Station	Years of data
54060 (Potford Brook @ Sandyford Bridge)	31
41016 (Cuckmere @ Cowbeech)	41
41028 (Chess Stream @ Chess Bridge)	44
36009 (Brett @ Cockfield)	38
30014 (Pointon Lode @ Pointon)	36
52015 (Land Yeo @ Wraxall Bridge)	29
20002 (West Peffer Burn @ Luffness)	41
39017 (Ray @ Grendon Underwood)	42
39036 (Law Brook @ Albury)	32
31025 (Gwash South Arm @ Manton)	30
52016 (Currypool Stream @ Currypool Farm)	38
36010 (Bumpstead Brook @ Broad Green)	41
43019 (Shreen Water @ Colesbrook)	35
45013 (Tale @ Fairmile)	24
TOTAL	502

Pyford Brook viaduct heterogeneity – following review

3.5.1 The pooling group was found to be strongly heterogeneous. Review of alternative sites indicate it is unlikely the quality of the pooling group will be improved by using stations further down the list generated in WinFap.

Pyford Brook viaduct goodness of fit details

Fitting	Z values
Generalised Logistic	5.32
Generalised Extreme Value	2.37
Pearson Type III	2.35
Generalised Pareto	-3.79

The permeable adjustment method assumes that the flood growth curve follows a Generalised Logistic distribution. On average the Generalised Logistic distribution is considered to perform better than the GEV for pooled growth curve derivation. In this instance the Generalised Logistic distribution has been selected.

Pyford Brook viaduct growth curves

Flood event	Rural (GL)	Urban (GL)
1 in 2 (50%)	1.00	1.000
1 in 10 (10%)	1.81	1.740
1 in 20 (5%)	2.14	2.062
1 in 50 (2%)	2.62	2.531
1 in 75 (1.33%)	2.84	2.760
1 in 100 (1%)	3.01	2.932
1 in 200 (0.5%)	3.44	3.379
1 in 1000 (0.1%)	4.62	4.638

Pyford Brook viaduct growth curve parameters

Growth curve	Location	Scale	Shape	Bound
Rural GL	1.00	0.31	-0.14	-1.30
Urban GL	1.00	0.28	-0.17	-0.65

Bourne Brook viaduct (Bourne Brook)

Subject catchment information	
Crossing	Bourne Brook @ 188_L1 (Cr06)
National grid reference	410850, 314150
Area	28.47km^2
Permeability	Not permeable (BFIHOST < 0.75 and SPRHOST > 20%)
Urbanisation	Urban (URBEXT2000 > 0.03)
Target return period	100
Required years of data	500

Bourne Brook viaduct default pooling group

Name	nYears	L-CV	L-Skew	Discordancy	Distance
43019 (Shreen Water @ Colesbrook)	35	0.20	0.00	0.45	0.45
41028 (Chess Stream @ Chess Bridge)	44	0.22	0.18	0.78	0.51
36010 (Bumpstead Brook @ Broad Green)	41	0.43	0.24	2.59	0.53
41020 (Bevern Stream @ Clappers Bridge)	39	0.23	0.22	1.03	0.54
52015 (Land Yeo @ Wraxall Bridge)	29	0.30	0.11	0.26	0.56
45013 (Tale @ Fairmile)	24	0.21	0.20	1.55	0.58
31025 (Gwash South Arm @ Manton)	30	0.28	0.08	0.22	0.58
30015 (Cringle Brook @ Stoke Rochford)	32	0.25	0.17	0.40	0.62
40017 (Dudwell @ Burwash)	39	0.21	-0.12	1.97	0.63
26803 (Water Forlornes @ Driffield)	9	0.22	-0.07	0.55	0.65
36009 (Brett @ Cockfield)	38	0.26	-0.10	0.90	0.68
41016 (Cuckmere @ Cowbeech)	41	0.33	0.10	0.84	0.70
28058 (Henmore Brook @ Ashbourne)	12	0.23	0.01	0.91	0.73
20002 (West Peffer Burn @ Luffness)	41	0.29	0.02	0.73	0.78
7006 (Lossie @ Torwinny)	19	0.28	0.11	0.13	0.78
39033 (Winterbourne st @ Bagnor)	46	0.34	0.40	2.69	0.80
TOTAL	519				
Weighted means		0.27	0.11		

Bourne Brook viaduct pooling group review

Comment	Information	Decision	Station years
Discordant sites	None		
Period of record (<8 years?)	26803 (Water Forlornes @ Driffield) has 9 years of data	Although record is short, it is > 8 years. Not enough evidence to remove based on the short record alone.	519
Assessment of sites flagged on the HiFlows-UK database as 'No Pooling' and No Pooling / No QMED' and sites with permeable catchments or major catchment differences.	43019 (Shreen Water @ Colesbrook) Scatter in high flow gaugings. Drowns early. Uncertainty in the rating at high flows.	Retain – not enough information to remove	519
	41028 (Chess Stream @ Chess Bridge) No gaugings for verification of rating, possible bypassing and drowning.	Retain – not enough information to remove	519
	52015 (Land Yeo @ Wraxall Bridge) Doubt in rating at higher flows, unconfirmed by gaugings.	Retain – not enough information to remove	519

Comment	Information	Decision	Station years
	45013 (Tale @ Fairmile) Doubts about data quality, significant scatter in gaugings pre-1999. Post 1999 EM gauge installed – may not measure flows <7 cumecs accurately.	Retain – not enough information to remove.	519
	31025 (Gwash South Arm @ Manton) Modular limit is approx 15 m3/s and highest flows may exceed this, with bypassing.	Retain – not enough information to remove	516
	30015 (Cringle Brook @ Stoke Rochford) Qmed is above the wing wall level and the modular limit of the weir. The rating includes an allowance for drowning using assumed positions of d/s weirs and sluices.	Retain – some uncertainty in the rating but not enough information to remove	516
	40017 (Dudwell @ Burwash) High flow rating based on gaugings, but does not take account of bypassing or drowning.	Retain – some uncertainty in the rating but not enough information to remove	516
	26803 (Water Forlornes @ Driffield) Station data poor quality. High flow rating is very poor and needs to be reviewed.	Remove – Remove due to poor data quality and short record	507
	41016 (Cuckmere @ Cowbeech) No gaugings at highest flows, high flows often out of bank.	Retain – not enough information to remove	507
	28058 (Henmore Brook @ Ashbourne) Unsure of modular limit and gaugings not to a high enough level.	Retain – not enough information to remove	507
	7006 (Lossie @ Torwinny) Geographically distant (located in the north of Scotland), affected by ice. Not suitable for estimation of QMED or pooling; control is sensitive to floods.	Remove – Geographically distant, differences in catchment and poor data	488
	39033 (Winterbourne st @ Bagnor)	Retain	484

Bourne Brook viaduct added stations

Name	nYears	L-CV	L-Skew	Discordancy	Distance
53017 (Boyd @ Bitton)	35	0.25	0.13	0.08	0.81

Bourne Brook viaduct reviewed pooling group

Station	Years of data
43019 (Shreen Water @ Colesbrook)	35
41028 (Chess Stream @ Chess Bridge)	44
36010 (Bumpstead Brook @ Broad Green)	41
41020 (Bevern Stream @ Clappers Bridge)	39
52015 (Land Yeo @ Wraxall Bridge)	29
45013 (Tale @ Fairmile)	24

Station	Years of data
31025 (Gwash South Arm @ Manton)	30
30015 (Cringle Brook @ Stoke Rochford)	29
40017 (Dudwell @ Burwash)	39
36009 (Brett @ Cockfield)	38
41016 (Cuckmere @ Cowbeech)	41
28058 (Henmore Brook @ Ashbourne)	12
20002 (West Peffer Burn @ Luffness)	41
39033 (Winterbourne st @ Bagnor)	42
53017 (Boyd @ Bitton)	35
TOTAL	519

Bourne Brook viaduct heterogeneity – following review

3.5.2 The pooling group was found to be strongly heterogeneous. Review of alternative sites indicate it is unlikely the quality of the pooling group will be improved by using stations further down the list generated in WinFap.

Bourne Brook viaduct goodness of fit details

Fitting	Z values
Generalised Logistic	3.33
Generalised Extreme Value	0.41
Pearson Type III	0.48
Generalised Pareto	-5.60
The permeable adjustment method assumes that the flood growth curve follows a Generalised Logistic distribution. On average the Generalised Logistic distribution is considered to perform better than the GEV for pooled growth curve derivation. In this instance the Generalised Logistic distribution has been selected.	

Bourne Brook viaduct growth curves

Flood event	Rural (GL)	Urban (GL)
1 in 2 (50%)	1.000	1.000
1 in 10 (10%)	1.685	1.668
1 in 20 (5%)	1.962	1.943
1 in 50 (2%)	2.352	2.332
1 in 75 (1.33%)	2.537	2.516
1 in 100 (1%)	2.672	2.653
1 in 200 (0.5%)	3.018	3.002
1 in 1000 (0.1%)	3.939	3.942

Bourne Brook viaduct growth curve parameters

Growth curve	Location	Scale	Shape	Bound
Rural GL	1.00	0.27	-0.12	-1.24
Urban GL	1.00	0.26	-0.13	-1.02